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FLIGHT EVALUATION - J-TEC AIRSPEED SYSTEM

Floyd Dominick, et al

Army Aviation Systems Test Activity
Edwards Air Force Base, California

April 1974

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Airspeed calibration tests were conducted on the J-TEC Associates, Inc. Model VA-210 true airspeed sensor to determine its suitability for operational and flight test use as a helicopter and V/STOL aircraft airspeed instrument. The J-TEC system operates on the principle of counting vortices shed by a bluff body (cylindrical post) in the airstream. Testing was conducted by the United States Army Aviation Systems Test Activity at Edwards Air Force Base, California, between

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20. Abstract.

17 November 1972 and 19 March 1973. The evaluation required 17.3 productive flight test hours. Wind tunnel tests were conducted in the Army wind tunnel at the National Aeronautics and Space Administration Center, Moffett Field, California. J-TEC personnel provided installation, maintenance and technical support. The system was tested on an NUH-1C helicopter at five different airframe locations. Emphasis was placed on the low-speed regime. The sensor had no direction-sensing capability and was mounted to detect only forward speed for all tests. The sensor has a true airspeed capability from less than 2 knots to 140 knots in undisturbed airflow. The best location of those evaluated was on the left FM antenna boom. This location provided a usable true airspeed indication down to 5 knots forward airspeed. The system evaluated is marginally acceptable for operational use and unacceptable for flight test use, primarily due to the lack of direction-sensing capability. A system is under development that measures flow angle and airspeed using the same basic principle. It should be evaluated when it becomes available. The J-TEC system has the following desirable characteristics: small size, light weight, simplicity, and low cost; minimal power requirements; no moving parts; and a true airspeed output in both digital and analog form which is unaffected by atmospheric variables.

PREFACE

The authors wish to express their appreciation to J-TEC Associates, Inc. for the excellent support provided for installation, checkout, troubleshooting and technical advice. In particular, Mr. Robert Campbell of J-TEC Associates was very helpful. There was no support contract provided.

In addition to the authors, USAASTA personnel participating in the evaluation included MAJ Robert K. Merrill, MAJ John R. Smith, and CPT Morrie Larson, evaluation pilots; Mr. Salvador Gomez, aircraft crew chief; Mr. James K. Slack, instrumentation technician; and SP-4 Alexander J. Krynytzky and Mr. Steven G. Dorris, engineering technicians.

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INTRODUCTION

BACKGROUND

1. Historically, the lack of accurate low-airspeed information (below 40 knots) has handicapped helicopter and V/STOL flight tests. In 1968, a request for proposal was issued (ref 1, app A) for design and development of a low-airspeed system suitable for use during engineering flight tests of helicopter and V/STOL aircraft. The requirement was for the system to measure and display lateral and rearward airspeed from zero to 40 knots and forward airspeed from zero to 250 knots. The Aeroflex true airspeed vector system was selected for further development. The United States Army Aviation Systems Command (AVSCOM) Test Request No. 71-30 (ref 2) authorized the United States Army Aviation Systems Test Activity (USAASTA) to conduct theoretical or actual flight evaluations of low-airspeed systems for V/STOL aircraft. Three prototype low-airspeed systems have previously been tested by USAASTA under Project No. 71-30. In addition to the Aeroflex true airspeed vector system, two other prototype systems, the single-axis Elliott low-airspeed system, and the LORAS II airspeed system are reported in references 3, 4 and 5. The purpose of this evaluation was to determine the suitability of the J-TEC model VA-210 true airspeed system for flight test and operational use.

2. Standard aircraft airspeed systems use a pitot-static probe to measure flight speed. These systems usually have a fixed pitot probe and static port which only sense the airstream dynamic pressure when aligned with the direction of flight. In the low-airspeed regime (below 20 to 40 knots, depending on the aircraft) the pitot-static pressure fluctuates excessively and the system is unusable. An airspeed system commonly used for flight testing incorporates a swiveling pitot-static probe which has approximately 20 degrees of angular freedom from the center line and, thus, can align with the airflow. However, this system is also unusable at low forward airspeeds and during sideward or rearward flight.

3. The J-TEC true airspeed system is manufactured by J-TEC Associates Inc. of Cedar Rapids, Iowa. The system is a recent, company-funded development and was not available for the original low-airspeed system design competition (ref 1, app A). The J-TEC true airspeed system is presently being used as a subsystem on several flight director and helicopter stabilization systems. In 1972 the United States Army Electronics Command (ECOM) procured a J-TEC system for use during their flight director tests. They requested that USAASTA calibrate and evaluate the system as part of the low true airspeed systems evaluations (Project No. 71-30).

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TEST OBJECTIVES

4. The general objective was to determine the adequacy of the J-TEC system as a helicopter airspeed instrument. The specific objectives were as follows:

a. Determination of sensor performance in low-speed forward flight.

b. Determination of sensor performance in high-speed forward flight.

c. Determination of sensor performance at various locations on the helicopter.

d. Evaluation of effects of ground proximity, angle of sideslip, and angle of attack on sensor performance.

e. Acquisition of data for further development of an omnidirectional airspeed system.

DESCRIPTION

5. The J-TEC true airspeed system was tested on a NUH-1C helicopter, USA S/N 63-8684. A detailed description of the UH-1C helicopter is contained in the operator's manual (ref 6, app A). The J-TEC model VA-210 system consists of a sensor and an electronics unit. Optional equipment includes an airspeed indicator, and a direction vane (model VA-300), intended for a ground wind measuring system. Manufacturer's specifications are presented in table 1. System components are shown in photo 1.

Theory of Operation

6. The J-TEC Associates true airspeed system operates on the aerodynamic phenomenon of vortex shedding from a bluff body. In past empirical studies, it has been found that the frequency of the shed vortices is proportional to the velocity of the fluid, regardless of the fluid density. The relationship between the vortex frequency and the fluid velocity referred to as the Strouhal number is defined as:

$$S = \frac{fd}{V}$$

S = Strouhal number.

f = Vortex frequency, in cycles per second.

d = Diameter of the post used to generate the vortices in feet.

V = Fluid velocity (TAS), in feet per second.

Table 1. J-TEC Model VA-210 Specifications.[1]

Item	Specification
Maximum speed	150 knots
Threshold	1 knot
Accuracy	±1 percent
Response	0.01 second
Output frequency	70 Hz/knot
Output analog voltage	50 MV/knot
Direction sensing	None
Power requirement	12 to 28 VDC, 200 MA
Size:	
Sensor	2-1/4 x 3-1/4 x 4 in.
Electronics	3-1/2 x 3-1/2 x 6 in.
Gage	Std 3-in. panel hole
System weight	Less than 4 pounds
Price	Less than $1000

[1]Based on manufacturer's specification (ref 7, app A).

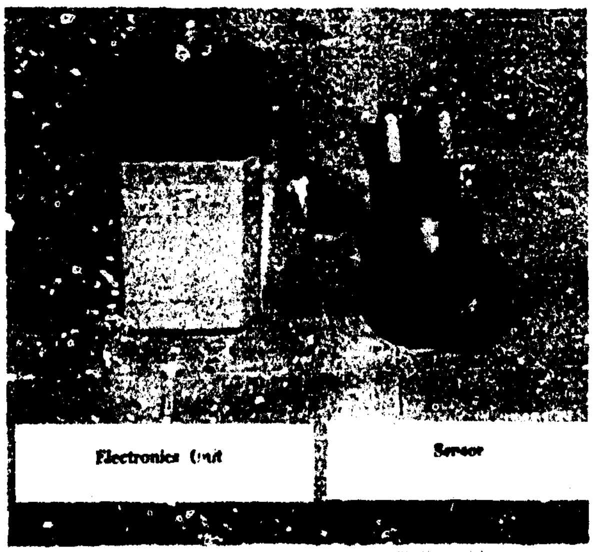


Photo 1. J-TEC Components.

The Strouhal number is independent of fluid density and is constant for Reynolds numbers ranging from less than 100 to more than 10,000. For speed regimes from 1 to 150 knots, the J-TEC sensor is, therefore, also independent of fluid viscosity. With the same electronics package, the usable velocity range can be shifted by changing the post diameter. Since the Strouhal number is independent of fluid viscosity and density, the vortex frequency varies linearly with velocity for a fixed post diameter.

7. In the J-TEC sensor, a cylindrical post is used to generate the vortices. The shedding frequency is sensed as it modulates an acoustical carrier signal generated by a crystal contained in one of the struts and received by a crystal in the opposite strut, as shown in figure A. The transmitted signal is modulated one cycle per vortex pair. In a digital system, this signal could be used directly. In the present system, a frequency to analog converter provides a direct current signal with its output voltage proportional to fluid velocity, or true airspeed. A block diagram of the signal flow is shown in figure B.

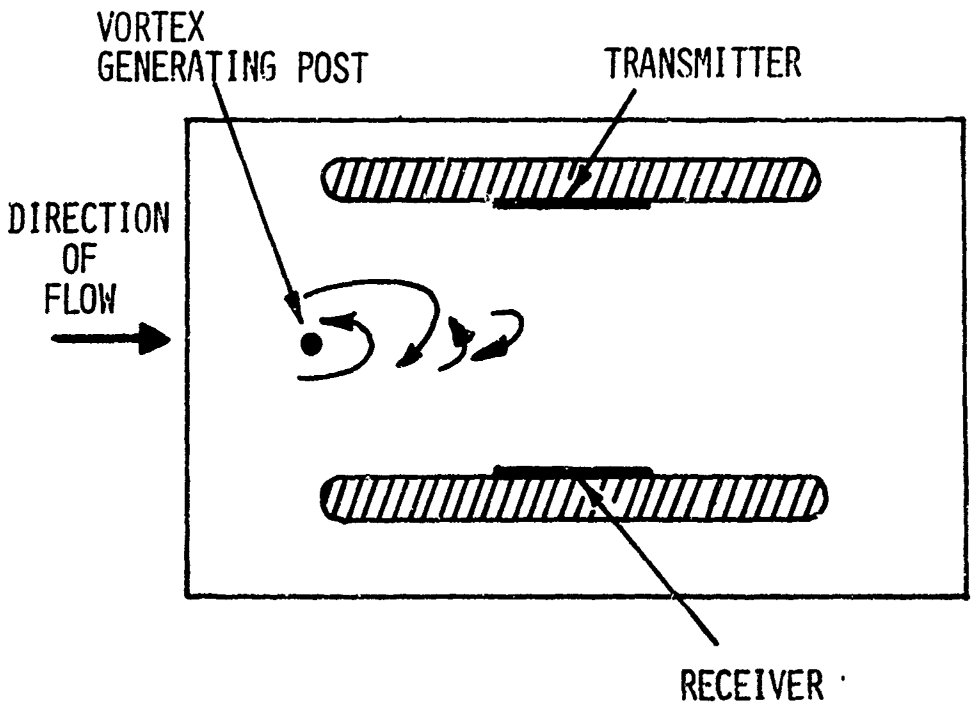


Figure A. J-TEC Sensor Operation.

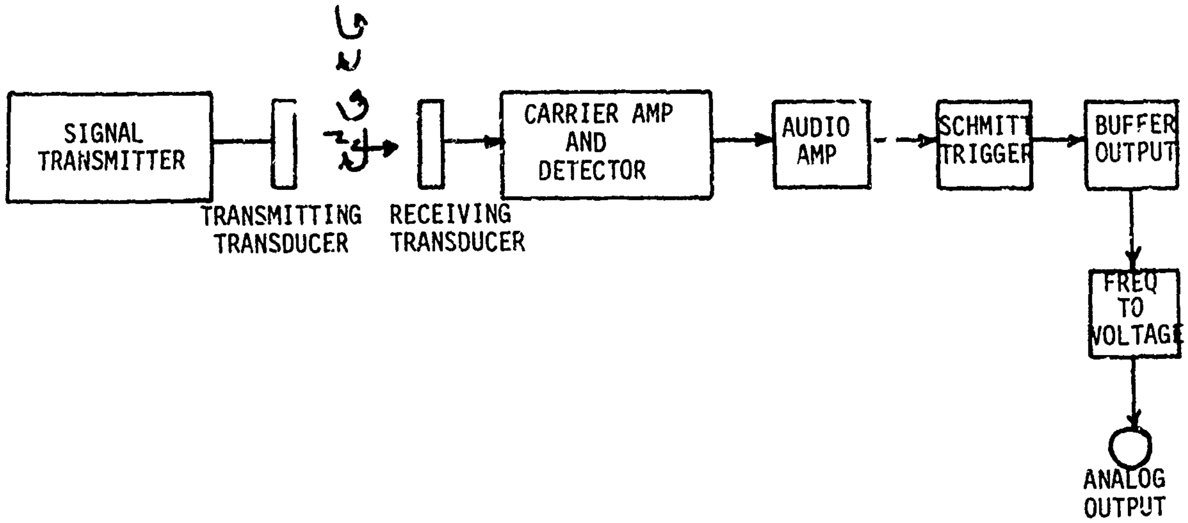


Figure B. Block Diagram of J-TEC System.

8. In addition to the basic sensor described previously, two modifications to the sensor were evaluated. The first had a double-post configuration, one in front of and one behind the sensor axis, so that flow in either direction would be sensed. There was no means to tell the flow direction and this configuration was abandoned. The second configuration had a single post and transition strips located on the inlet lip. The strips were added to cause early flow transition (from laminar to turbulent) along the sensor walls to eliminate a slope change in the calibration when transition occurred. There was a high minimum threshold (approximately 8 knots) and development was not continued. The third configuration on which most of the testing was accomplished had a single post and smooth sensor walls.

TEST SCOPE

9. The J-TEC Model VA-210 true airspeed system was tested by USAASTA at Edwards Air Force Base, California between 17 November 1972 and 19 March 1973. These tests consisted of 15 flights for 17.3 productive hours. Two of these flights were made with the modified sensors described in paragraph 8. The remainder were made with the basic sensor. Test conditions were within the flight envelope contained in the operator's manual (ref 6, app A). All flights were conducted at a mid center-of-gravity location, an approximate gross weight of 6700 pounds and a rotor speed of 324 rpm. The system was flown at conditions

shown in tables 2 and 3. High-speed data were limited to approximately 80 knots true airspeed (KTAS) by the data acquisition system. Subsequent to the flight tests, the sensor was evaluated in the United States Army Air Mobility Research and Development Laboratory (USAAMRDL) 7 by 10 foot wind tunnel at the National Aeronautics and Space Administration (NASA) Ames Research Center, Moffett Field, California. The tests were conducted from minimum tunnel speed to maximum J-TEC sensor speed and over the maximum angle capability of the J-TEC system.

Table 2. Nominal Low-Speed Flight Conditions.[1]

Flight Condition	Parameter Variation
Longitudinal flight OGE[2]	35 KTAS rearward to 40 KTAS forward
Longitudinal flight IGE[3]	Zero to 40 KTAS, forward
Lateral flight OGE	35 KTAS, left and right
10-KTAS forward flight OGE	Zero to 45°, left and right sideslip
20-KTAS forward flight OGE	Zero to 45°, left and right sideslip
30-KTAS forward flight OGE	Zero to 45°, left and right sideslip

[1]Field elevation: 2800 feet.
[2]Out of ground effect (OGE), skid height: 50 feet.
[3]In ground effect (IGE), skid height: 5 feet.

Table 3. Nominal High-Speed Flight Conditions.[1]

Flight Condition	True Airspeed (kt)	Sideslip (deg)	Vertical Speed (fpm)
Level	20 to 105	Zero	Zero
Level	50	Zero to 30, left and right	Zero
Level	100	Zero to 15, left and right	Zero
Climb	50	Zero	500 to 1500
Descent	50 and 100	Zero	500 to 2000

[1]Density altitude: 5000 feet.

10. The basic sensor was flight tested in five different locations on the helicopter as shown in figure 3 and appendix C. The locations were (1) on the forward portion of the cabin roof, (2) on the airspeed boom, (3) on the FM antenna boom, (4) under the forward fuselage, and (5) above the rotor mast. In locations 2 and 3 the sensor was oriented with the post both vertical and horizontal. In the other locations, the post was oriented only vertically. In all locations, the sensor was oriented to sense airflow from the front only (forward airspeed).

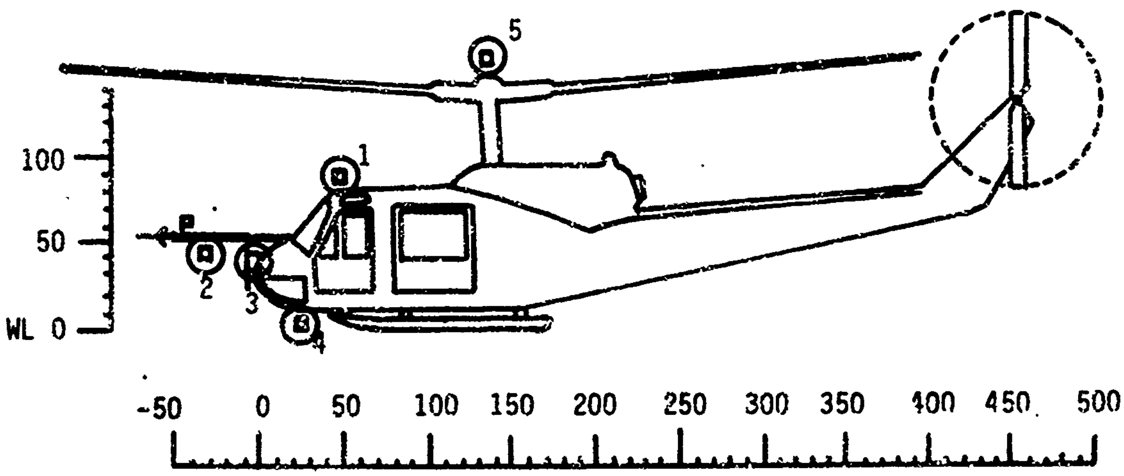


Figure C. Airspeed Sensor Position.

TEST METHODOLOGY

11. Evaluation of any new measurement system requires a valid reference standard. Prior to introducing flight variables, the J-TEC system was evaluated under ideal conditions by testing the electronic components with simulated inputs from laboratory equipment. The primary flight test method was to fly the aircraft near the ground both IGE and OGE, establishing ground speed with respect to a calibrated ground pace vehicle. Surface wind was measured using an anemometer for each data point. The ground speed and aircraft heading were corrected for prevailing wind direction and speed to obtain true airspeed and sideslip. This method was used for all low-speed conditions (table 2). At higher speeds, a boom-mounted, swiveling pitot-static probe was used as the airspeed reference. The boom airspeed system was calibrated in level flight, climbs, and descents using a trailing bomb. Boom-mounted vanes were used to measure sideslip and angle of attack. The J-TEC analog voltage output was recorded in 8-bit digital format on magnetic tape. This was the primary data source for the J-TEC system. A J-TEC cockpit indicator was evaluated on one flight. The aircraft was stabilized at each test condition and data were recorded for approximately 10-second data recording periods. Future low-speed system evaluations should include quantitative evaluations of accuracy and response during dynamic maneuvers such as takeoffs, landings, accelerations, etc. This will require a radar or other space positioning system with an accurate time correlation capability.

RESULTS AND DISCUSSION

GENERAL

12. Two basic problems are inherent to measuring low airspeed of a helicopter or V/STOL aircraft. First is the ability to measure low dynamic pressure or flow velocity. The second problem is to operate in, or correct for, the highly disturbed flow field around the aircraft, particularly at low speeds. Present pitot-static systems suffer from both these problems and are unusable below 20 to 40 KTAS, depending on the aircraft. Wind tunnel and laboratory data indicated that the J-TEC system solved the first problem adequately, having a threshold of less than 2 KTAS. This threshold was confirmed during the flight test. The solution to the second problem involves two elements: the character of the local flow for a given sensor's location, and the sensitivity of the sensor to that flow. Therefore, the primary goal was to find a location where the J-TEC, in combination with the local flow characteristics, would yield repeatable output which varied only with relative free stream airspeed at the lowest possible true airspeed.

13. The J-TEC system was not designed to provide omnidirectional airspeed information or to meet specified low-airspeed system requirements. The tests show the concept to be feasible and that potential exists for a compact, lightweight, low-cost true airspeed system which is unaffected by atmospheric variables. Five different locations of the sensor were evaluated. All provided repeatable output at airspeeds down to some threshold value where rotor wash or disturbed flow was encountered. These threshold airspeeds varied from more than 20 KTAS to approximately 5 KTAS. Below the threshold airspeed, highly random output occurred, with indicated values up to 40 KTAS. It was also found that sensor operation was affected by sensor orientation. The sensor was less sensitive to the disturbed flow and random output with the sensor oriented with the post horizontal rather than vertical. Of those evaluated, the best location was on the FM antenna boom with the sensor oriented horizontally. Even in this location, there was some fluctuation in the 10 to 15-knot range. The mean value was repeatable, indicating that proper filtering or damping would provide a usable output. The one flight made with the J-TEC airspeed indicator qualitatively showed adequate damping.

14. Ground effect tended to decrease the sensitivity in the low-speed range. Variation in angle of attack and sideslip angle had different effects depending on sensor location. Wind tunnel and flight test results showed that the sensor generally sensed the magnitude of the resultant airspeed vector to the angle limits of the sensor and not the component airspeed. This would preclude mounting four sensors orthogonally to measure direction components. This lack of direction-sensing capability was the major inadequacy of the system. The minimum speed sensing capability (5 knots) was unacceptable for flight test use and would be marginally acceptable for operational use. It is probable that a better location for speed sensing

could be found with additional testing. The maximum speed capability (140 KTAS) of the sensor, determined from wind tunnel tests, covered the range of the test aircraft, but fell 10 knots short of the manufacturer's specification and 110 KTAS short of the low true airspeed system design requirement of 250 KTAS (ref 1, app A). It should be noted that the J-TEC system was not designed to that requirement.

EARLY MODEL EVALUATION

15. Two variations of the basic sensor were evaluated early in the program and eliminated as unacceptable. One variation of the sensor had a double-post configuration, one in front of, and one behind the ultrasonic beam. This allowed flow in either direction through the sensor to cause vortices which would be sensed. There was no means, however, to determine the flow direction. For this scheme to work, a single post with two sets of acoustic transducers would be needed: one set of transducers to indicate flow in each direction.

16. The second variation rejected had transition strips attached to the sensor inlet walls. The purpose of these strips was to cause early flow transition (from laminar to turbulent) to eliminate a change in slope in the calibration curve at approximately 60 KTAS, where transition normally occurred. This sensor design resulted in an unacceptably high threshold speed of approximately 8 KTAS (fig. 1). A cockpit airspeed indicator was available for this flight, and qualitatively exhibited good damping with adequate response.

FORWARD AND REARWARD FLIGHT

17. The forward and rearward flight tests were conducted at the conditions listed in tables 2 and 3. Forward and rearward flight results are shown in figures 1 through 6, appendix B. The sensor was oriented to sense only forward speed for all of these flights. The J-TEC sensor was not expected to provide usable output in rearward flight. The rearward flight points were flown primarily for other low-airspeed sensors which were being evaluated simultaneously. They do, however, provide some useful information relative to the J-TEC sensor. The rearward points give an indication of the general flow at the particular location. For example, on figure 2 for the FM antenna boom location, the data are relatively stable, with little variation in indicated speed during the points. The mean indicated speed did not exceed 6 KTAS. This indicates the local air flow at this location is relatively stable, whereas figure 6 for the rotor mast location shows a large variation in speed indication, from 5 to 36 KTAS, with mean values as high as 25 KTAS. This indicates highly disturbed or random flow at this location. The rearward flight data also provide information for the minimum reliable forward flight speed for a given location. For example, although the rotor mast location (fig 6) gives usable

output down to less than 10 KTAS in forward flight, rearward flight (tail winds) gives mean speed indications as high as 25 KTAS. The aircraft could have a relative airspeed of 17 KTAS backward with a forward speed indication of 25 KTAS. Therefore, in this location speed indications could not be relied on below 25 KTAS.

18. The forward flight position error varied considerably with each location and orientation. All locations produced approximately linear calibrations, which is desirable both for test and operational use. For both the FM antenna boom vertical orientation and the airspeed boom horizontal locations the position error was negative, as shown in figures 3 and 4, appendix B. In these positions, the indicated values approach the minimum threshold of the sensor (2 to 3 KTAS). However, these indicated values were reached at approximately 15 to 20 KTAS, which is therefore the minimum usable speed. The rotor mast location (fig. 6) has a positive position error; however, it was unacceptable, as discussed in paragraph 17. The belly location (fig. 5) has a near-zero mean error at speeds below 15 KTAS. However, it has a discontinuity from 15 to 20 KTAS and large variation from 5 to 20 KTAS. These characteristics make it an undesirable location. The FM antenna boom location with the sensor horizontal (fig. 2) produced the most acceptable calibration of those evaluated. It has a usable threshold of approximately 5 KTAS. There is also a relatively small variation while transitioning into the rotor wake and a small transition range (10 to 15 KTAS). This location provides a marginally acceptable speed indication for operational use but would be unacceptable for flight test. It is possible that more acceptable locations exist. As system development is continued, efforts should be made to determine a more suitable location.

GROUND PROXIMITY EFFECTS

19. In-ground-effect tests were accomplished only for low-speed forward flight at a skid height of 5 feet, for the conditions listed in table 2. Generally, ground proximity gave a lower indicated airspeed for a given forward speed when compared to OGE results. This indicated speed decrease varied from zero for the belly location to a maximum of 5 KTAS for the FM antenna boom location. Ground effect also tended to increase the fluctuation in indicated airspeed during stabilized flight conditions.

SIDEWARD FLIGHT

20. Sideward flight tests were conducted at conditions listed in table 2. Results are shown in figures 7 through 11, appendix B. For all locations the sensor was oriented to measure the forward component of airspeed; therefore, no direct results were expected in sideward flight. However, as with the rearward flights, some useful information applicable to the J-TEC system can be obtained. For example, figure 7 for the FM antenna boom location with the sensor horizontal, shows that the

forward indicated speed threshold of 5 KTAS was not exceeded until the lateral component exceeded 20 KTAS. Above 20 KTAS in sideward flight to the left, increasing lateral speeds produced greater indicated forward speed. As with rearward flight, sideward flight data for the rotor mast location (fig. 11) show a large variation or random longitudinal flow with no actual free stream forward airspeed component.

SIDESLIP EFFECTS

21. Sideslip tests were conducted at conditions shown in tables 2 and 3. Results are shown in figures 12 through 15, appendix B. For the FM antenna boom location at a nominal airspeed of 10 KTAS, there was essentially no effect of sideslip on indicated airspeed. As airspeed was increased airspeed error became larger with sideslips in either direction, reaching a value of approximately 1/2 knot per degree of sideslip at 40 KTAS and above. For the airspeed boom location, the same trend existed; however, it was of much less magnitude, reaching approximately 1 knot per 10 degrees of sideslip. For the belly location the effect was reversed with airspeed error decreasing with sideslip in either direction at 10 KTAS and having essentially no effect at higher speeds. Sideslip tended to increase the variation in output, both during stabilized and transient conditions. The variation was even larger for the rotor mast location. The effects of sideslip are highly dependent on sensor location and airspeed.

CLIMB AND DESCENT EFFECTS

22. Climb and descent tests were conducted at conditions shown in table 3. Results are shown in figures 16 through 19, appendix B. The effects of angle-of-attack variation attained by climbing and descending appeared to be primarily a function of sensor mounting orientation. With the sensor mounted horizontally on the FM antenna boom and airspeed boom (figs. 16 and 17) the mean variation was small (less than ±4 KTAS mean variation). Variation was random with no apparent trends. With the sensor mounted vertically, the airspeed error became more negative as angle of attack was either increased or decreased from level flight conditions. This effect was largest for the mast location (fig. 19). As with other tests, the mast location exhibited large fluctuations in indicated airspeed compared to other locations.

WIND TUNNEL TESTS

23. The J-TEC sensor was tested in the USAAMRDL 7 by 10 foot wind tunnel at the NASA Ames Research Center to determine its characteristics with relation to pitch, yaw and airspeed in undisturbed flow. The sensor was tested at indicated airspeeds of 10 to 100 knots in 5-knot increments, and from 100 knots to the sensor limits in 10-knot increments and at pitch angles and yaw angles to the

sensor limits. Angle limits were defined by a rapid decrease in output with increase in angle. The results of the test are shown in figures 20 through 23, appendix B.

24. Figures 20 and 21, appendix B, show the output for velocity change while maintaining pitch and yaw angles at zero degrees. Extrapolated wind tunnel results show a minimum threshold of approximately 2 KTAS. The sensor output was linear up to an airspeed of 60 KTAS with a slope of 90 MV/knot. From 60 KTAS to 130 KTAS, the output was linear with a changed slope of 71 MV/knot. This change in sensitivity at 60 KTAS was also observed in-flight. The calibration constants obtained from the wind tunnel were considerably different from the contractor's calibration constants (68 MV/knot), which were used to prepare figures 1 through 19, appendix B.

25. Figure 22, appendix B, shows the sensor output with yaw angle change at constant wind tunnel velocities of 50 and 102 KTAS. At 50 KTAS, there was a slight deviation in output from zero degrees to 30 degrees left, and 40 degrees right yaw. At yaw angles above 30 degrees, left, and 40 degrees, right, the deviations in output were large and made the sensor unusable. The 102-KTAS data have the same characteristics as the 50-KTAS data, except for sideslip limits being 25 degrees, left, and 30 degrees, right.

26. Figure 23, appendix B, shows sensor outut for pitch change while maintaining constant tunnel velocities of 50 and 108 KTAS. At 50 KTAS the sensor output was approximately constant for positive pitch angles out to the sensor limits of 32.6 degrees. On the negative pitch angles at 50 KTAS the output dropped off slowly until the sensor limits were reached at 20 degrees. At 108 KTAS the sensor output reacted the same as at 50 KTAS, except that the negative angle-of-attack limit was 10 degrees. These limits in angle were achieved by rotating the sensor slowly. If abrupt angle changes were made, limits were reached at lower angles. For example, if the sensor was rapidly rotated from zero to 5 degrees pitch down, no usable output resulted. The sensor angle had to be reduced substantially to regain a usable output.

INSTALLATION, MAINTENANCE, RELIABILITY AND COST

27. Installation of the J-TEC system was simple. The system is small and lightweight, which facilitated convenient location. Installation consisted of fabricating a bracket to mount the sensor in the chosen location; mounting the sensor and electronics package; and running cabling from the electronics to the sensor, to a 28-volt DC power source, and to the data recording system for the output signal. Power requirements were minimal and were compatible with the aircraft system. The initial system did not provide positive cable connections, which are required for aircraft use. These were subsequently provided by the contractor. Initial system installation took approximately one man-day. Each subsequent relocation of the sensor required approximately 2 hours.

28. The system has stable electronics with both digital and analog output. During the course of the program no electronic balancing or adjustments were required. No other maintenance was required.

29. Several failures occurred early in the evaluation. The failures manifested themselves in two ways. The first was a complete lack of output signal. The second failure mode was an increase in minimum output signal equivalent to 8 to 10 knots airspeed. All failures were determined to be electronic component failures. On at least one occasion, the cause was found to be over-voltage (32 volts) from a ground power unit used for preflight activities. The system should be modified to incorporate over-voltage protection and to provide a failure warning. In two locations, aircraft UHF radio transmissions drove the output signal to full scale. Future J-TEC systems should be designed or installed to preclude electromagnetic interference.

30. A comparison of systems was made on the basis of prototype and projected production costs. The J-TEC system has the potential of costing significantly less than any other system tested during the project.

J-TEC OMNIDIRECTIONAL AIRSPEED SYSTEM

31. A system is under development by J-TEC Associates to measure flow angle as well as speed, using the same basic principle. In this system the post is replaced by a ring with varying cross-section diameter. At a given speed, the frequency will change with flow angle due to the varying cross section. By comparing the frequency generated from the varying cross-section ring to one of constant cross section, both speed and angle can be determined. Preliminary data from the contractor indicate this new system can determine the flow angle with an accuracy of ±5 degrees. Speed measurement capability is unchanged. This system should be evaluated when it becomes available.

CONCLUSIONS

GENERAL

32. The J-TEC system was not designed to provide omnidirectional airspeed information or to meet specified low-airspeed system requirements. The tests show the concept to be feasible and that potential exists for a compact, lightweight, low-cost true airspeed system which is unaffected by atmospheric variables.

33. The following specific conclusions were reached as a result of these tests:

a. The J-TEC cockpit airspeed indicator qualitatively exhibited good damping with adequate response (para 16).

b. For low-speed forward flight, the FM antenna boom location with the sensor horizontal produced the most acceptable calibration of all locations evaluated (para 18).

c. The J-TEC system provides data which are marginally acceptable for operational use and are unacceptable for flight test (para 18).

d. When mounted on the FM antenna boom, the J-TEC system provided reliable airspeed information down to 5 knots forward airspeed (para 18).

e. The sensor location and orientation are critical (paras 18, 20, 21, and 22).

f. Ground proximity tended to give lower indicated airspeeds and increased fluctuations during stabilized flight conditions (para 19).

g. Sideslip effects are highly dependent upon sensor location and airspeed (para 21).

h. Angle-of-attack effects appear to be primarily a function of sensor mounting and orientation (para 22).

i. In sideward flight, a forward airspeed component was indicated at all sensor locations and orientations (para 20).

j. In undisturbed airflow the threshold was approximately 2 KTAS and the maximum speed capability was 140 KTAS (para 24).

RECOMMENDATIONS

34. Future low-airspeed system evaluations should include quantitative evaluations of accuracy and response during dynamic maneuvers such as takeoffs, landings, accelerations, etc. (para 11).

35. As system development is continued, tests should be conducted to determine a more suitable location (para 18).

36. The J-TEC system should be modified to provide over-voltage protection and failure warning (para 29).

37. Future J-TEC systems should be designed or installed to preclude electromagnetic interference (para 29).

38. The directional J-TEC system should be evaluated when it becomes available (para 31).

APPENDIX A. REFERENCES

1. Request for Proposal, Air Force Flight Test Center, Edwards Air Force Base, California, RFP NR. F04611-68-R-0080.

2. Letter, AVSCOM, AMSAV-EF, 20 July 1971, subject: Flight Test of Low Airspeed Sensors.

3. Final Report, USAASTA, Project No. 71-30, *Flight Evaluation, Elliott Low Airspeed System, Low Airspeed Sensor Final Report I*. September 1972.

4. Final report, USAASTA, Project No. 71-30, *Flight Evaluation, Aeroflex Low Airspeed System, Low Airspeed Sensor Final Report II*, April 1973.

5. Final report, USAASTA, Project No. 71-30, *Flight Evaluation, Pacer Systems, Inc., LORAS II Airspeed System, Low Airspeed Sensor Final Report III*, January 1974.

6. Technical Manual, TM 55-1520-220-10, *Operator's Manual, Model UH-1C Helicopter*, April 1971.

7. Specification, J-TEC Associates, Inc., November 1972, Model VA-210, "True Airspeed Sensor No. 120 B."

APPENDIX B. TEST DATA [1,2]

INDEX

[1] Data in figures 1 through 11 are shown in terms of both indicated airspeed, using the nominal calibration supplied by the contractor, and analog voltage output. Correct airspeeds at the sensor can be determined by applying the wind tunnel calibration (fig. 20) to the analog voltage.

[2] The points within each symbol indicate the mean value during the recording period (approximately 10 seconds). Vertical lines associated with some data points indicate maximum variation in output during the recording period. The variation had different characteristics. In some cases, fairly smooth output occurred with a shift during the record. In other cases rapid random fluctuations occurred. No discernible frequency occurred. For points where variation is less than the symbol size no variation line is presented.

FIGURE 1
AIRSPEED CALIBRATION IN FORWARD AND REARWARD FLIGHT
J-TEC SENSOR VA 210 S/N K-72-17 NUH-1C USA S/N 63-8684

FM ANTENNA BOOM LOCATION-POST VERTICAL-TRANSITION STRIPS

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	SKID HEIGHT ~FT	FLIGHT CONDITION
□	6930	131.5	-.2	324.	1200	2.9	50	OGE LEVEL FLIGHT
○	6650	131.40	-.3	324.	1310	4.1	5	IGE LEVEL FLIGHT

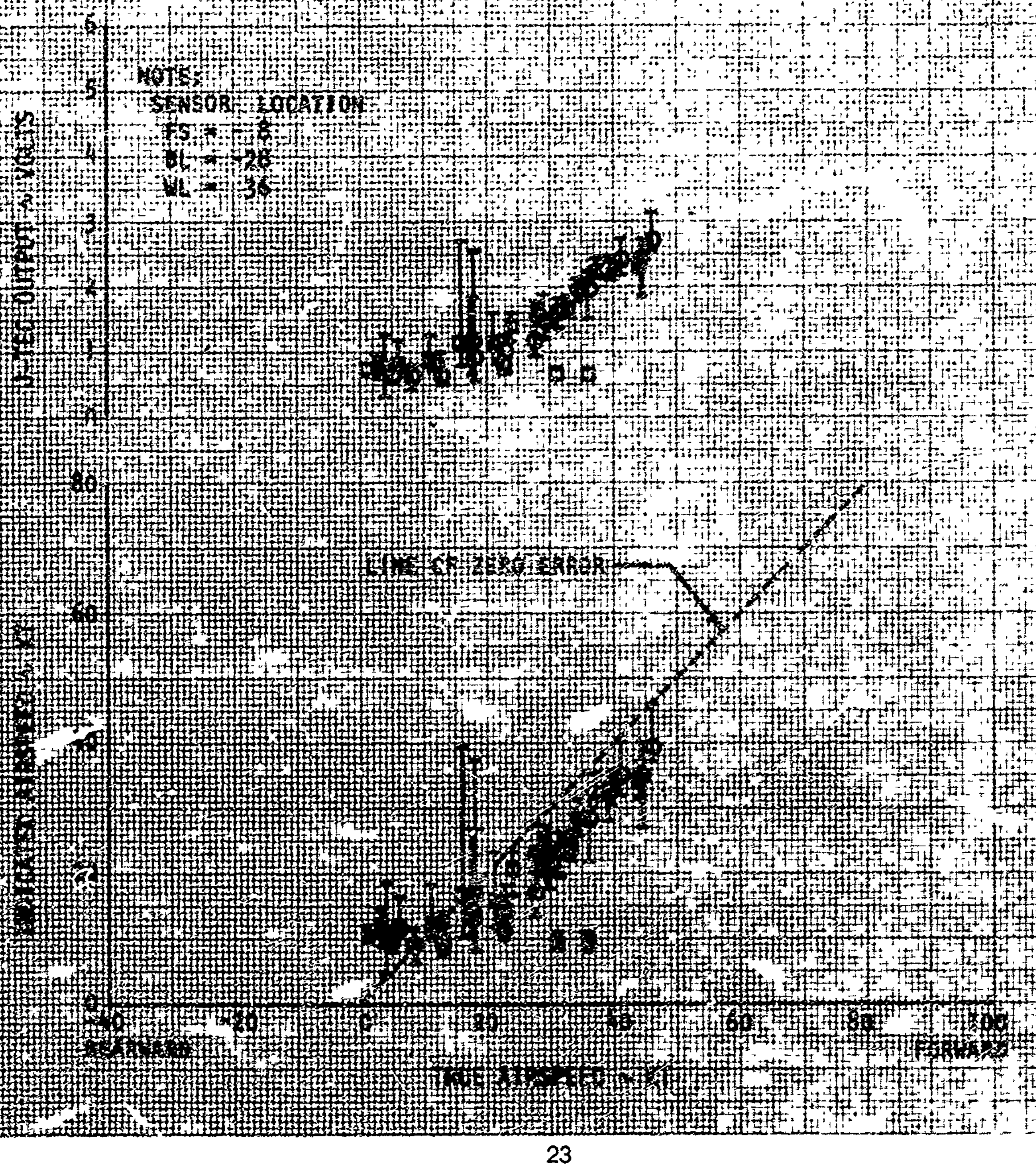


FIGURE 2

AIRSPEED CALIBRATION IN FORWARD AND REARWARD FLIGHT

J-TEC SENSOR VA 210 S/N L-72-18 NUH-1C USA S/N 63-8684

F ANTENNA BOOM LOCATION-POST HORIZONTAL

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	SKID HEIGHT ~FT.	FLIGHT CONDITION
□	7000	131.7	-.3	324.	480	-1.7	50	OGE LEVEL FLIGHT
○	6750	131.4	-.3	324.	660	-.8	50	OGE LEVEL FLIGHT
△	6700	131.4	-.3	324.	600	-.1	5	IGE LEVEL FLIGHT
◇	7030	132.2	-.3	324.	3980	2.4	>50	OGE LEVEL FLIGHT

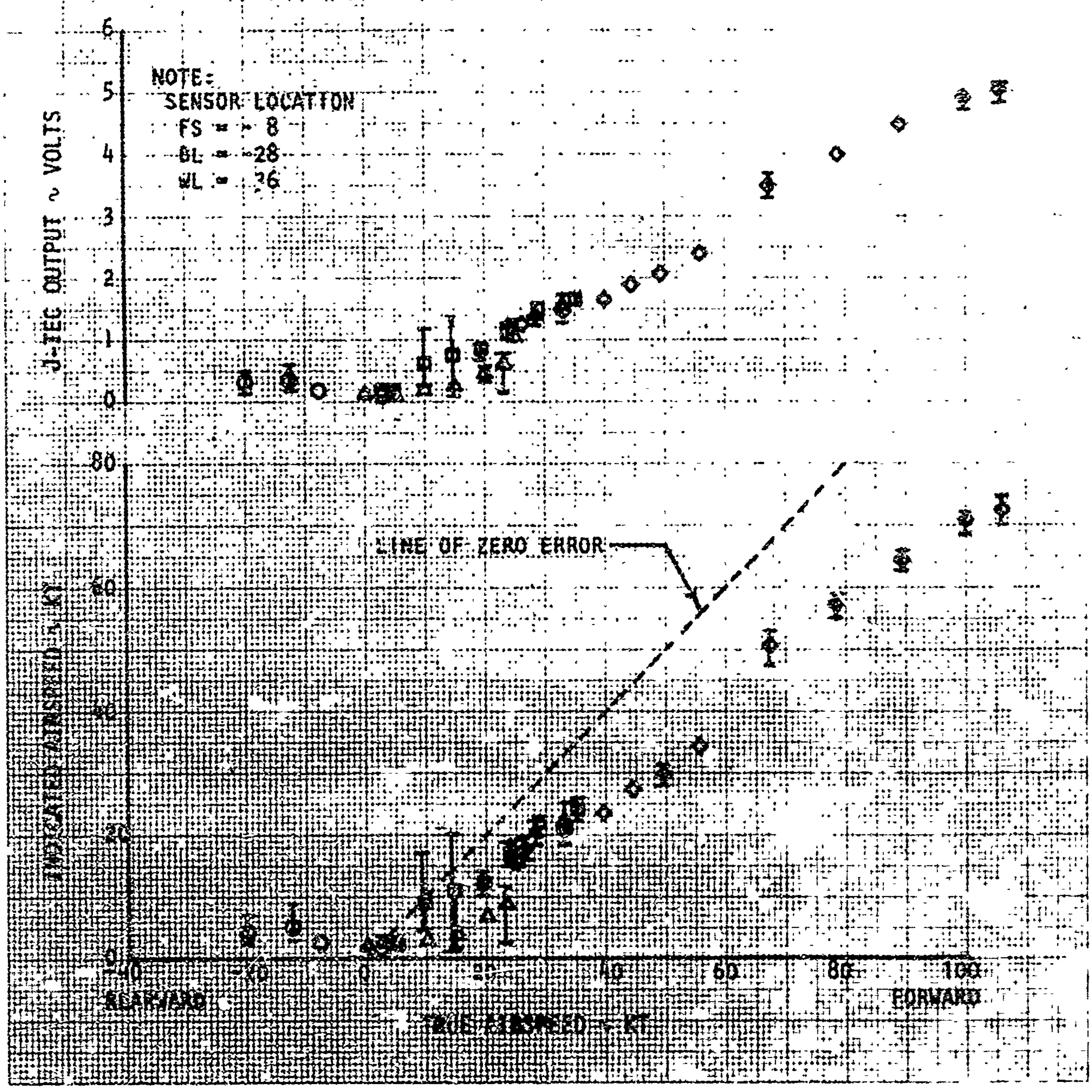


FIGURE 3
AIRSPEED CALIBRATION IN FORWARD AND REARWARD FLIGHT
J-TEC SENSOR VA 210 S/N L-72-18 NUH-1C USA S/N [illegible]
FM ANTENNA BOOM LOCATION-POST VERTICAL

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	SKID HEIGHT ~FT	FLIGHT CONDITION
□	6870	132.4	-.5	325.	2770	9.3	50	OGE LEVEL FLIGHT
○	6720	132.4	-.5	325.	2810	9.7	50	OGE LEVEL FLIGHT
△	6510	132.3	-.5	326.	2840	10.3	5	IGE LEVEL FLIGHT

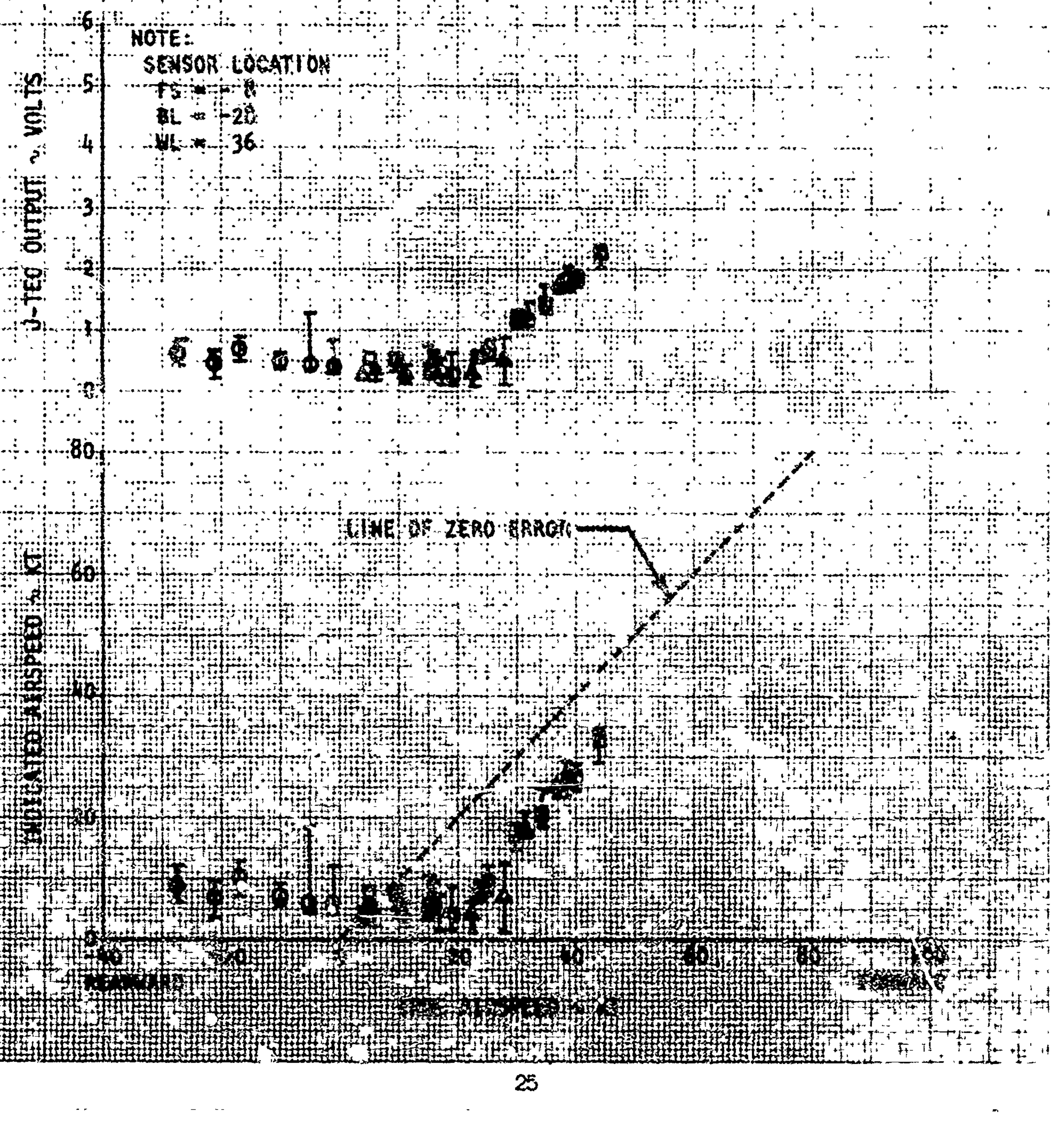


FIGURE 4
AIRSPEED CALIBRATION IN FORWARD AND REARWARD FLIGHT
J-TEC SENSOR VA 210 S/N L-72-18 NUH-1C USA S/N 63-8684

AIRSPEED BOOM LOCATION-POST HORIZONTAL

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	SKID HEIGHT ~FT	FLIGHT CONDITION
□	6960	132.3	-.6	326.	2500	6.4	50	OGE LEVEL FLIGHT
○	6820	132.3	-.6	327.	2470	6.1	50	OGE LEVEL FLIGHT
△	6630	132.2	-.6	325.	2440	6.4	5	IGE LEVEL FLIGHT
◇	6920	132.0	-.6	326.	4830	6.4	>50	OGE LEVEL FLIGHT

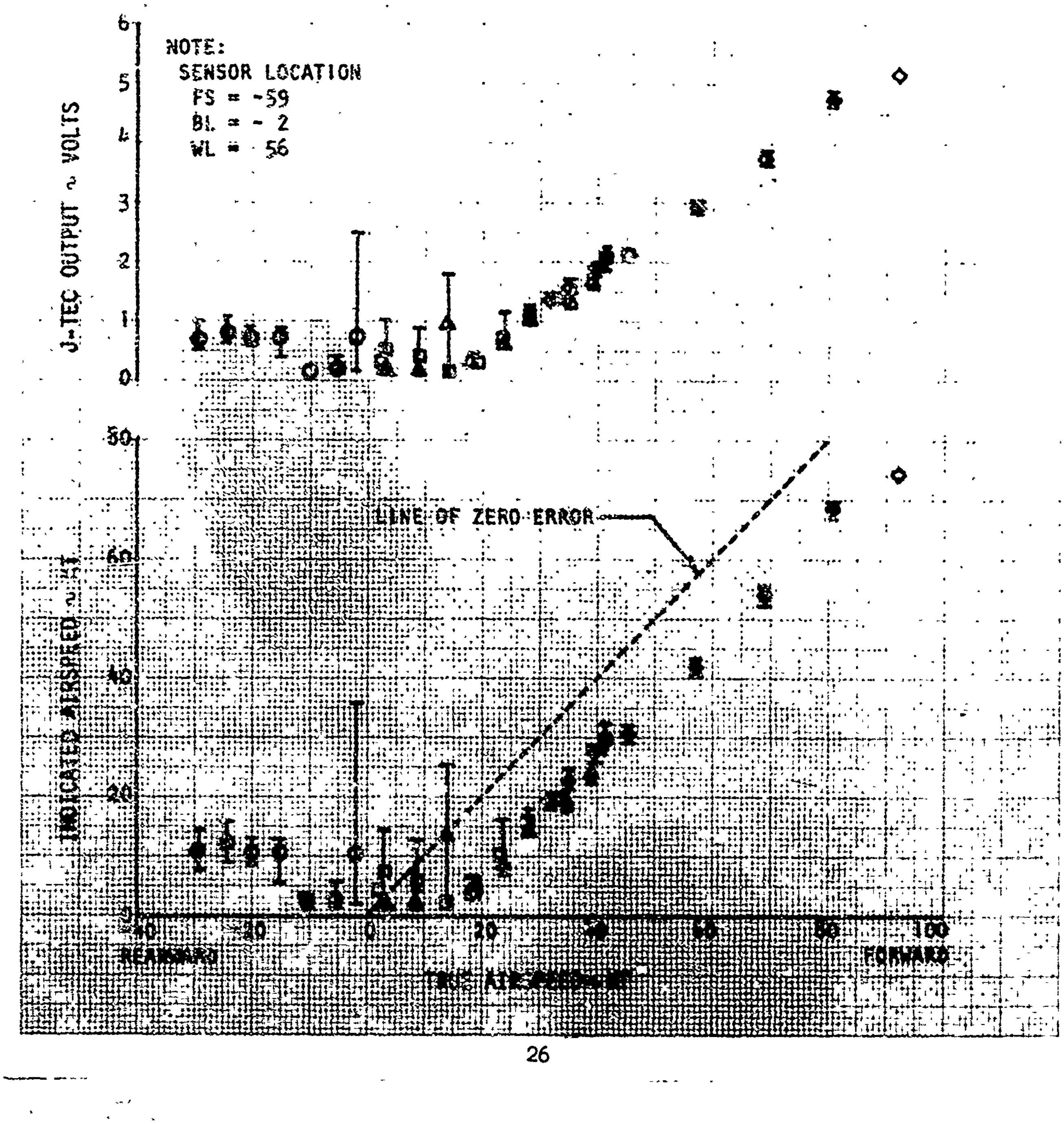


FIGURE 8

AIRSPEED CALIBRATION IN FORWARD AND REARWARD FLIGHT

S-TEC SENSOR VA-210 S/N L-72-18 NUH-1C USA S/N 63-8684

BELLY LOCATION-POST VERTICAL

SYMBOL	GROSS WEIGHT	CENTER OF GRAVITY LONG.	CENTER OF GRAVITY LATERAL	ROTOR SPEED	DENSITY ALTITUDE	AMBIENT TEMP	SKID HEIGHT	FLIGHT CONDITION
	LB	FS	BL	RPM	FT	°C	FT	
[illegible]	[illegible]	132.[illegible]	[illegible]	326	[illegible]350	8.0	[illegible]	[illegible] LEVEL FLIGHT
[illegible]	[illegible]	132.0	[illegible]	323	[illegible]	8.5	[illegible]	OGE LEVEL FLIGHT
[illegible]	[illegible]	131.[illegible]	[illegible]	324	[illegible]	8.5	5	IGE LEVEL FLIGHT
[illegible]	[illegible]	131.8	[illegible]	324	[illegible]	1.6	[illegible]	OGE LEVEL FLIGHT
[illegible]	[illegible]	132.1	[illegible]	325	[illegible]760	8.1	50	OGE LEVEL FLIGHT
[illegible]	[illegible]	132.5	[illegible]	325	2750	7.8	50	OGE LEVEL FLIGHT

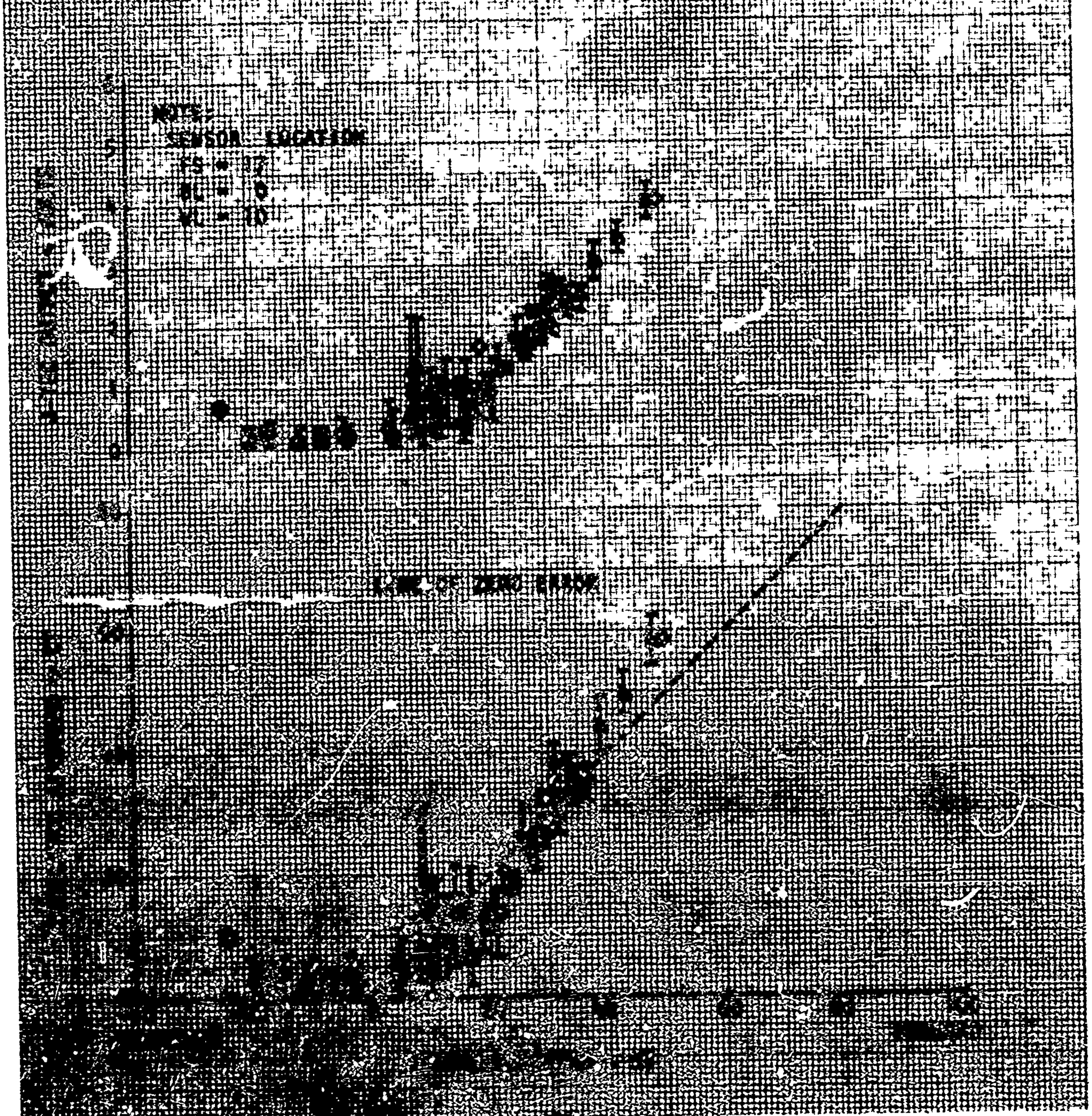


FIGURE 6

AIRSPEED CALIBRATION IN FORWARD AND REARWARD FLIGHT

J-TEC SENSOR VA 210 S/N L-72-28 NUH-1C USA S/N 63-8684

ROTOR MAST LOCATION-POST VERTICAL

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	SKID HEIGHT ~FT	FLIGHT CONDITION
□	6790	132.1	-.6	325	2670	11.4	50	OGE LEVEL FLIGHT
○	6560	132.0	-.7	325	2960	13.0	50	OGE LEVEL FLIGHT
△	6310	131.8	-.7	324	3020	14.1	5	IGE LEVEL FLIGHT
◇	7000	131.8	-.7	324	4970	6.9	>50	OGE LEVEL FLIGHT

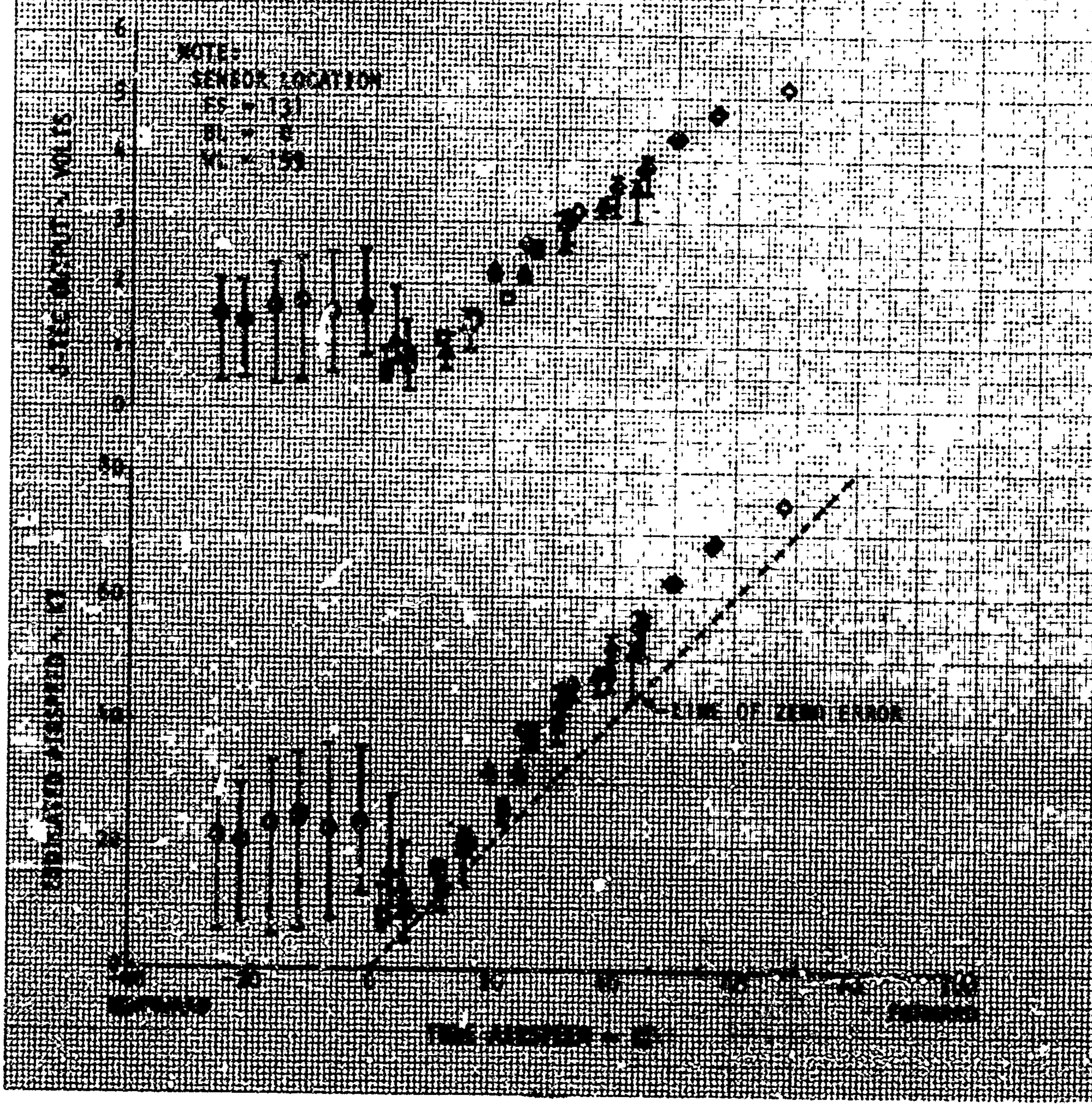


FIGURE 7

AIRSPEED CALIBRATION IN SIDEWARD FLIGHT

J-TEC SENSOR VA 210 S/N L-72-18 NUH-1C USA S/N 63-8684

FM ANTENNA BOOM LOCATION-POST HORIZONTAL

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	SKID HEIGHT ~FT	FLIGHT CONDITION
□	6790	131.5	-.3	324	610	-.8	50	OGE LEVEL FLIGHT

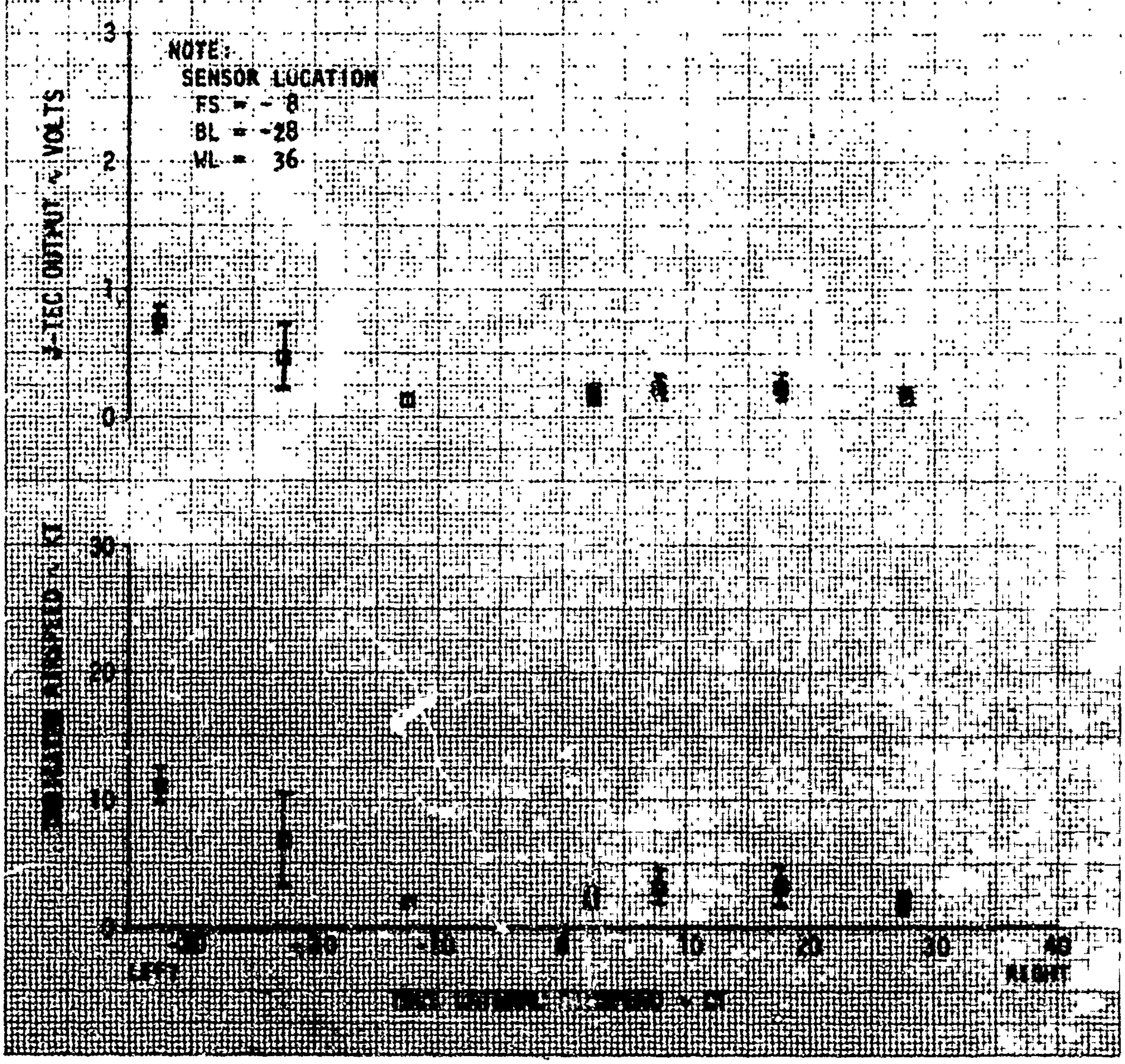


FIGURE 8

AIRSPEED CALIBRATION IN SIDEWARD FLIGHT

J-TEC SENSOR VA 210 S/N L-72-18 NUH-1C USA S/N 63-8684

FM ANTENNA BOOM LOCATION-POST VERTICAL

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	SKID HEIGHT ~FT	FLIGHT CONDITION
◻	6790	132.4	-.5	325.	2870	9.9	50	OGE LEVEL FLIGHT

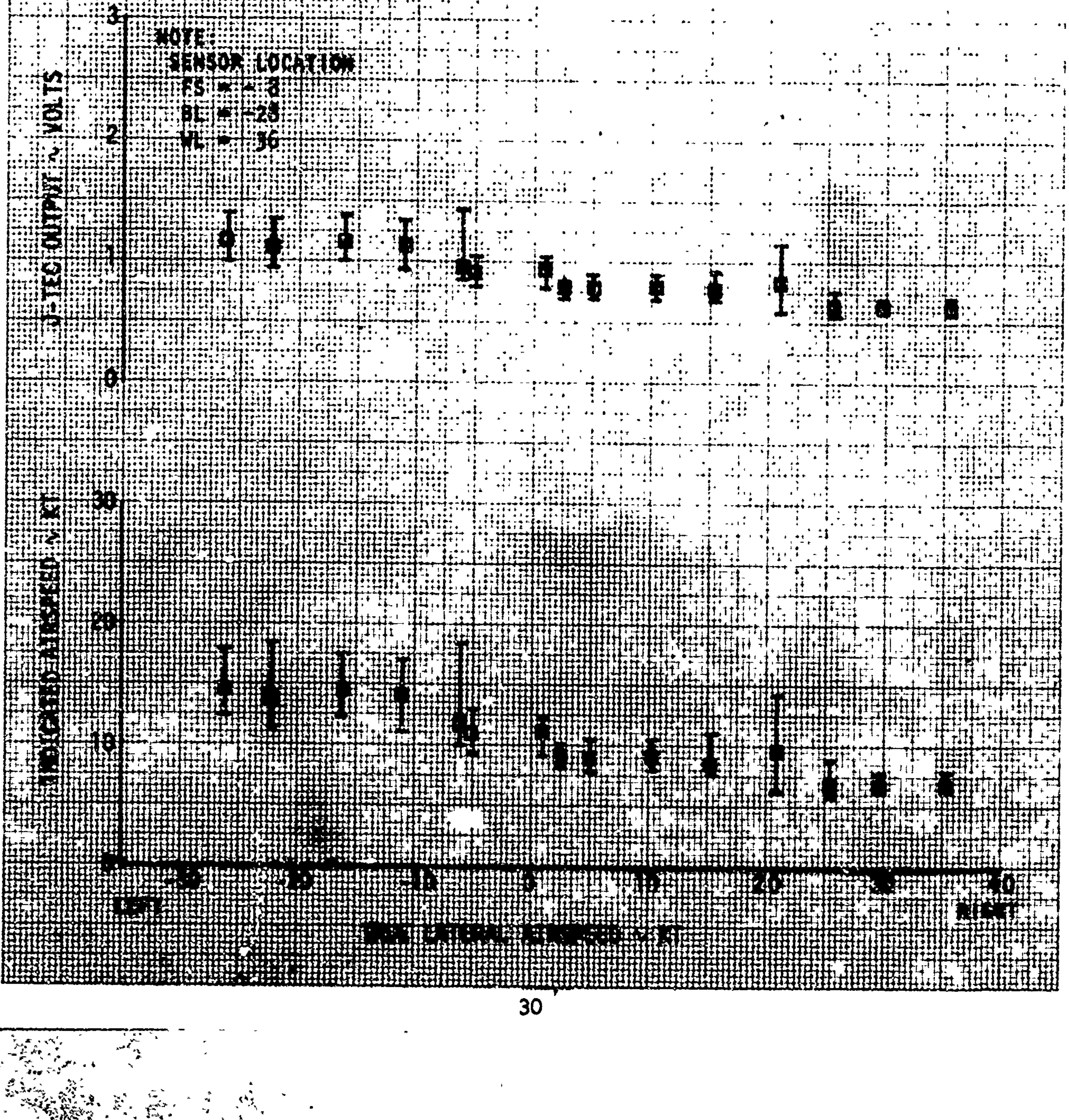


FIGURE 9

AIRSPEED CALIBRATION IN SIDEWARD FLIGHT

J-TEC SENSOR VA 210 S/N L-72-18 NUH-1C USA S/N 63-8684

AIRSPEED BOOM LOCATION-POST HORIZONTAL

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	SKID HEIGHT ~FT	FLIGHT CONDITION
□	6890	132.3	-.6	326.	2480	5.9	50	OGE LEVEL FLIGHT

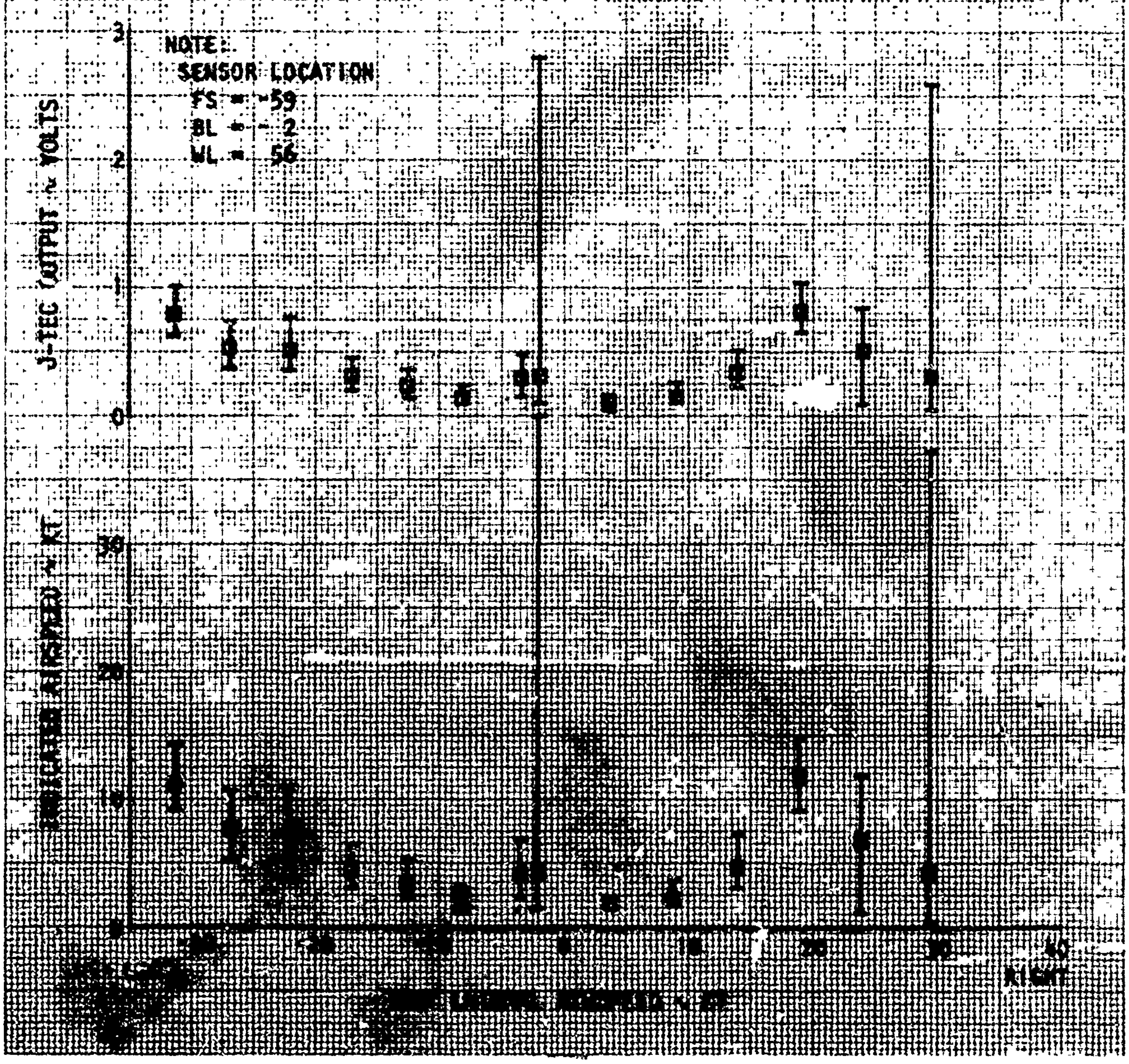


FIGURE 10
AIRSPEED CALIBRATION IN SIDEWARD FLIGHT
J-TEC SENSOR VA 210 S/N L-72-18 NUH-1C USA S/N 63-8684

BELLY LOCATION-POST VERTICAL

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	SKID HEIGHT ~FT	FLIGHT CONDITION
□	6770	132.1	-.4	325.	2810	8.3	50	OGE LEVEL FLIGHT
○	6790	132.1	-.4	325.	2480	8.4	50	OGE LEVEL FLIGHT

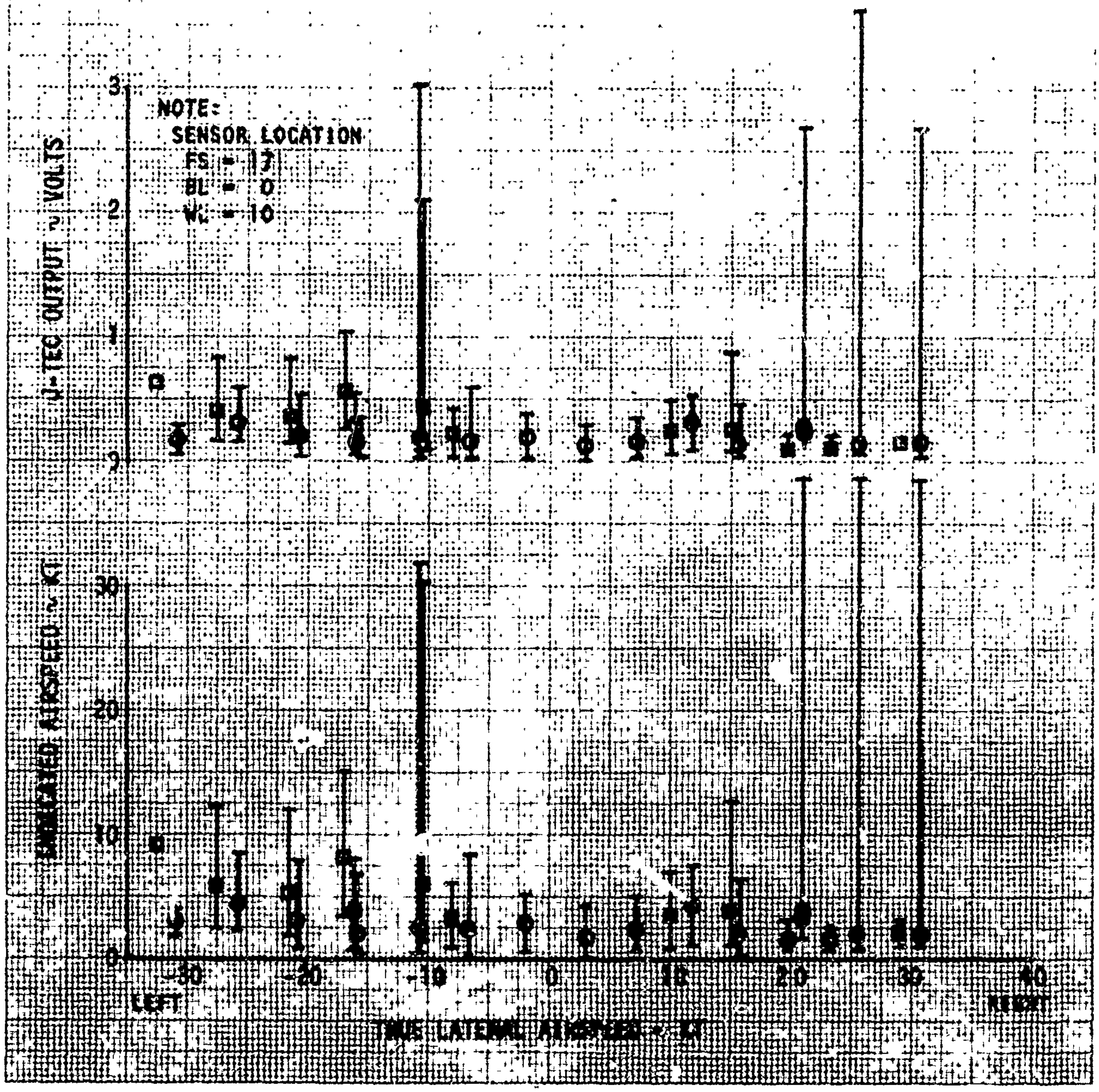


FIGURE 11
AIRSPEED CALIBRATION IN SIDEWARD FLIGHT

J-TEC SENSOR VA 210 S/N L-72-18 NUH-1C USA S/N 63-8684

ROTOR MAST LOCATION-POST VERTICAL

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	SKID HEIGHT ~FT	FLIGHT CONDITION
□	6690	132.0	-.6	325	2820	12.1	50	OGE LEVEL FLIGHT

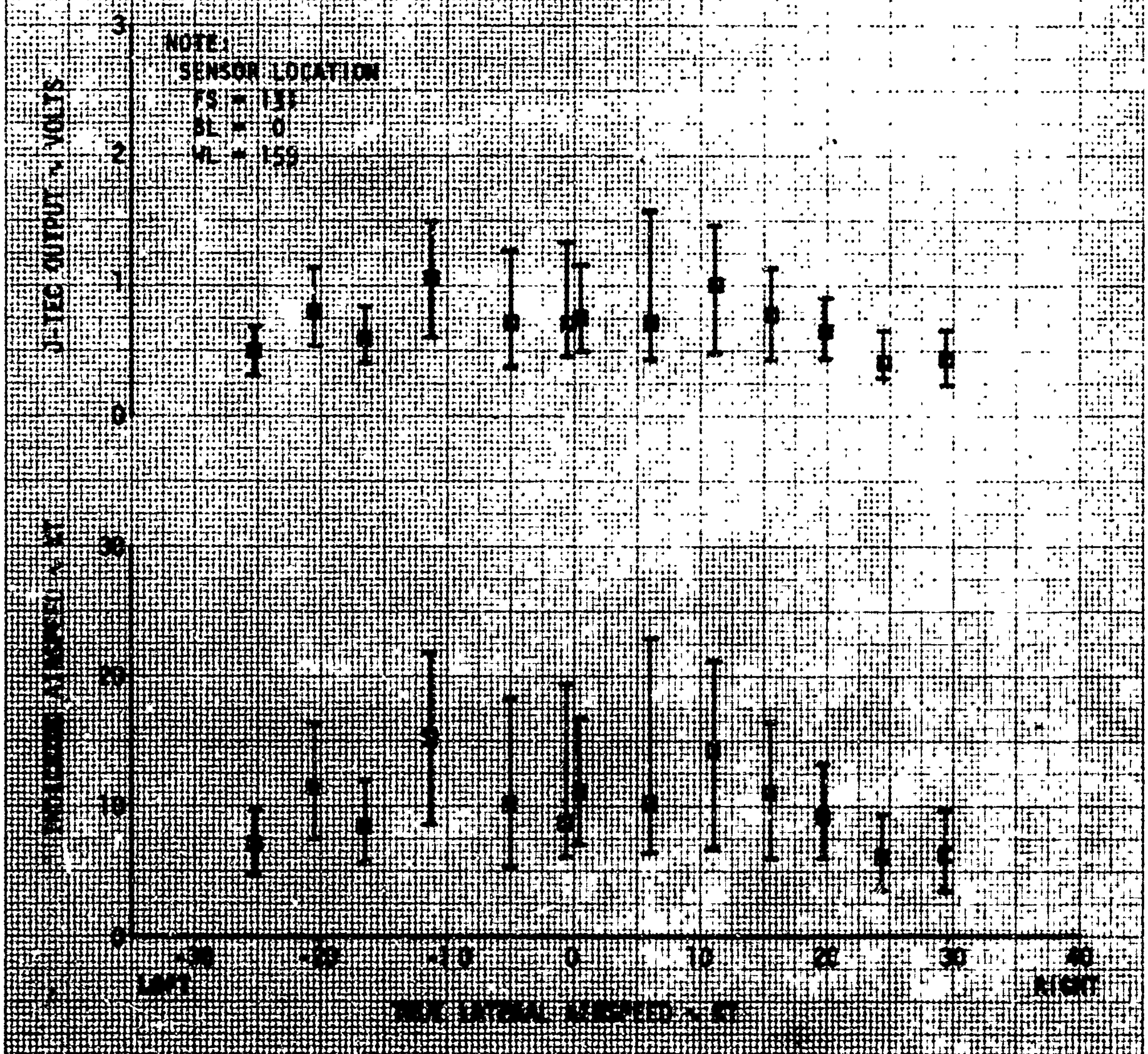


FIGURE 12

EFFECT OF SIDESLIP ON AIRSPEED ERROR

T-TEC SENSOR VA 210 S/N L-72-18 NUH-1C USA S/N 63-8684

FM ANTENNA BOOM LOCATION AFT HORIZONTAL

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	NOMINAL AIRSPEED ~KTAS	FLIGHT CONDITION
[illegible]	6660	132.3	-.5	324	2920	10.5	10	OGE LEVEL FLIGHT
[illegible]	6610	132.3	-.5	326	2920	9.9	20	OGE LEVEL FLIGHT
[illegible]	6380	132.3	-.5	325	2320	9.0	30	OGE LEVEL FLIGHT
[illegible]	6960	132.1	-.6	323	4070	5.0	60	OGE LEVEL FLIGHT
[illegible]	6880	132.1	-.5	324	3950	2.2	100	OGE LEVEL FLIGHT

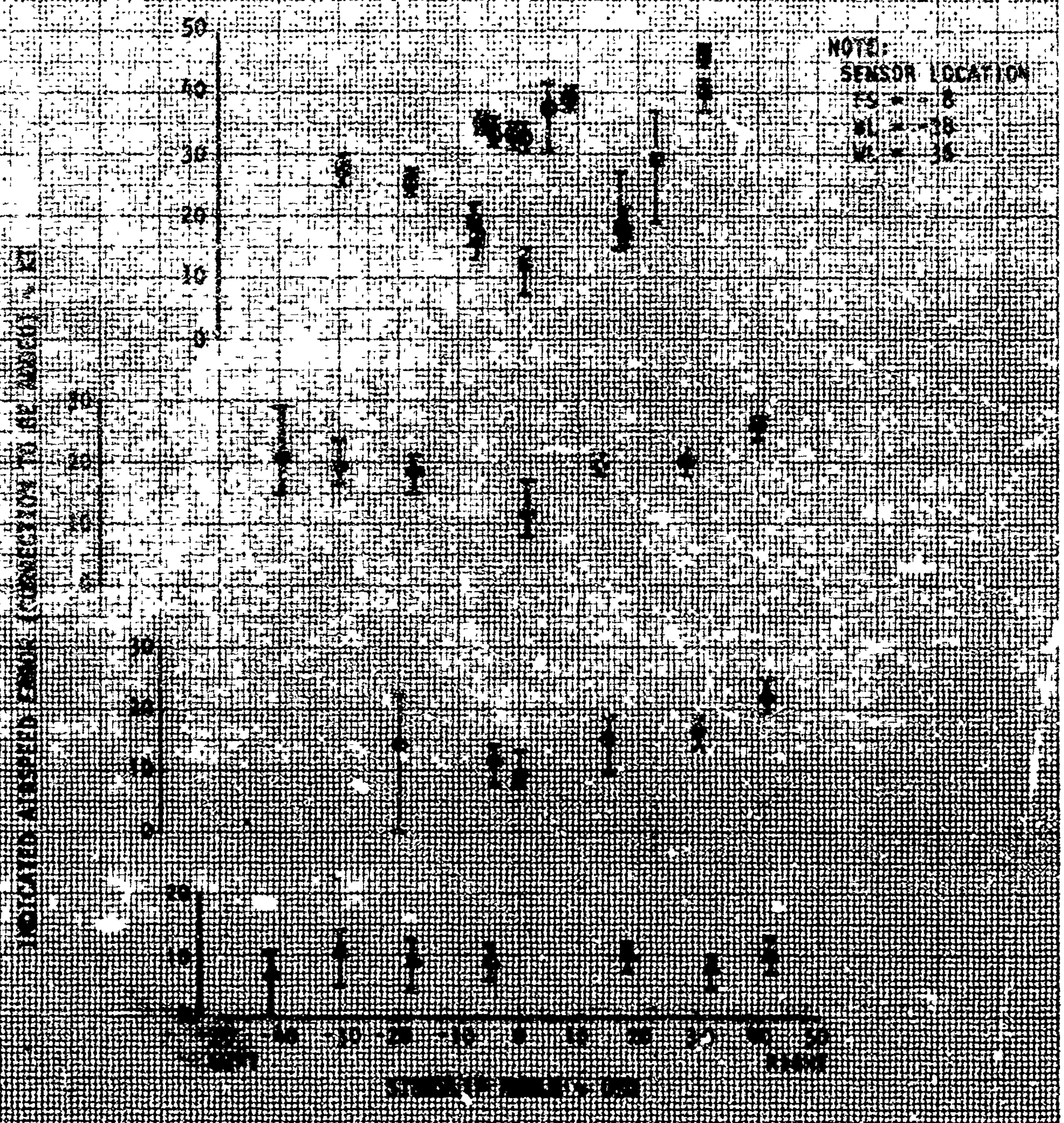


FIGURE 15
EFFECT OF SIDESLIP ON AIRSPEED ERROR
J-TEC SENSOR VK-310 S/N L-72-16 UH-1C USA S/N 63-8684
AIRSPEED BOOM LOCATION-POST HORIZONTAL

SYMBOL	GROSS WEIGHT LB	CENTER OF GRAVITY LONG FS	LATERAL BL	ROTOR SPEED RPM	DENSITY ALTITUDE FT	AMBIENT TEMP °C	NOMINAL AIRSPEED KTAS	FLIGHT CONDITION
○	[illegible]	[illegible]	[illegible]	326	[illegible]	[illegible]	10	OGE LEVEL FLIGHT
●	6720	[illegible]	[illegible]	324	2420	6.1	20	OGE LEVEL FLIGHT
■	[illegible]	132.2	-.6	326	[illegible]	6.0	30	OGE LEVEL FLIGHT
◇	6770	[illegible]	-.7	333	[illegible]	6.7	50	OGE LEVEL FLIGHT

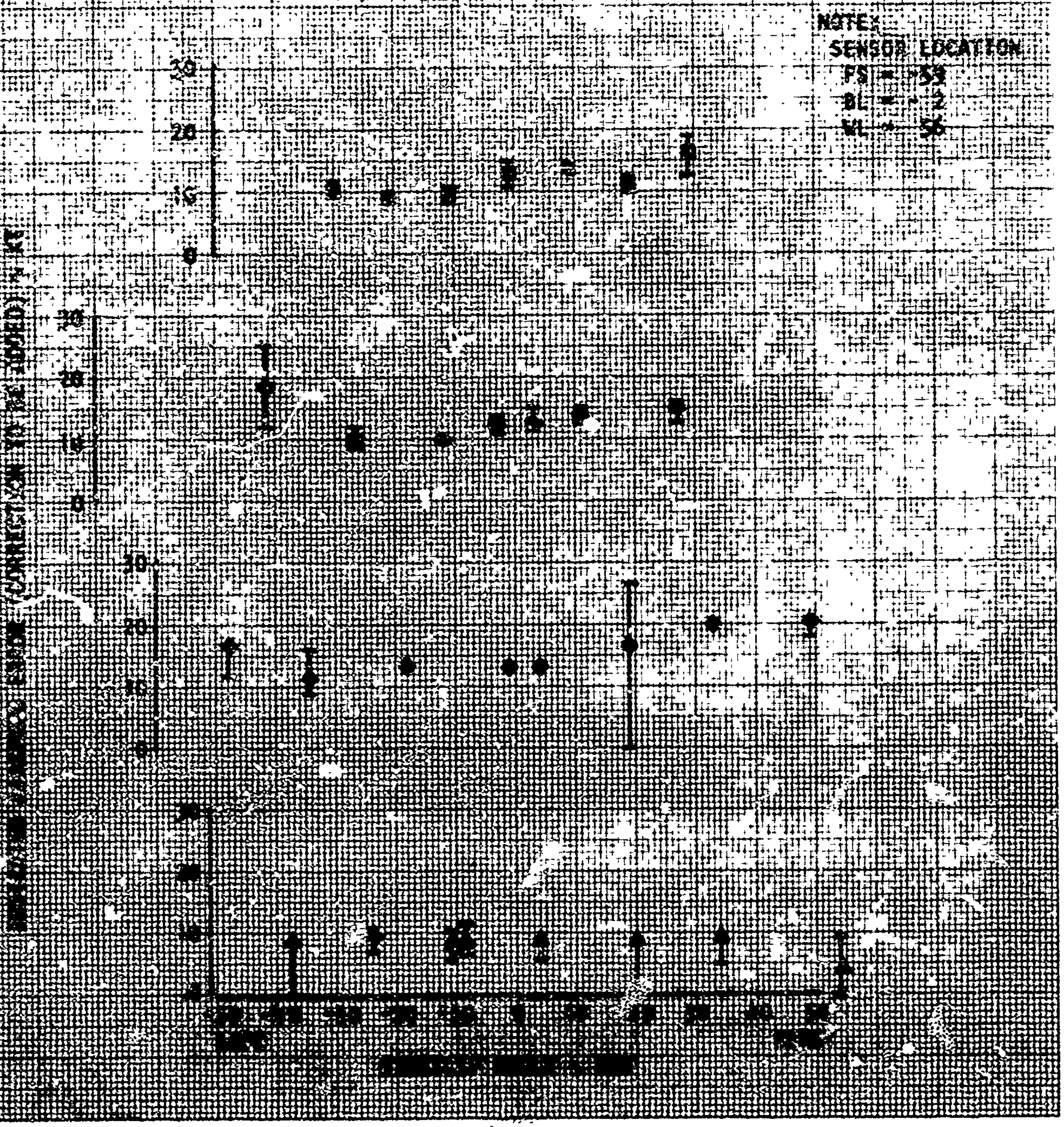


FIGURE 14
EFFECT OF SIDESLIP ON AIRSPEED ERROR
J-TEC SENSOR VA 210 S/N L-72-18 NUH-1C USA S/N 63-8684

BELLY LOCATION-POST VERTICAL

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	NOMINAL AIRSPEED ~KTAS	FLIGHT CONDITION
△	6690	132.0	-.5	321	2890	9.4	10	OGE LEVEL FLIGHT
◇	6620	132.0	-.5	324.	2850	8.8	20	OGE LEVEL FLIGHT
O	6580	132.0	-.5	325.	2820	8.6	30	OGE LEVEL FLIGHT
□	6350	132.0	-.5	325.	4840	1.4	50	OGE LEVEL FLIGHT

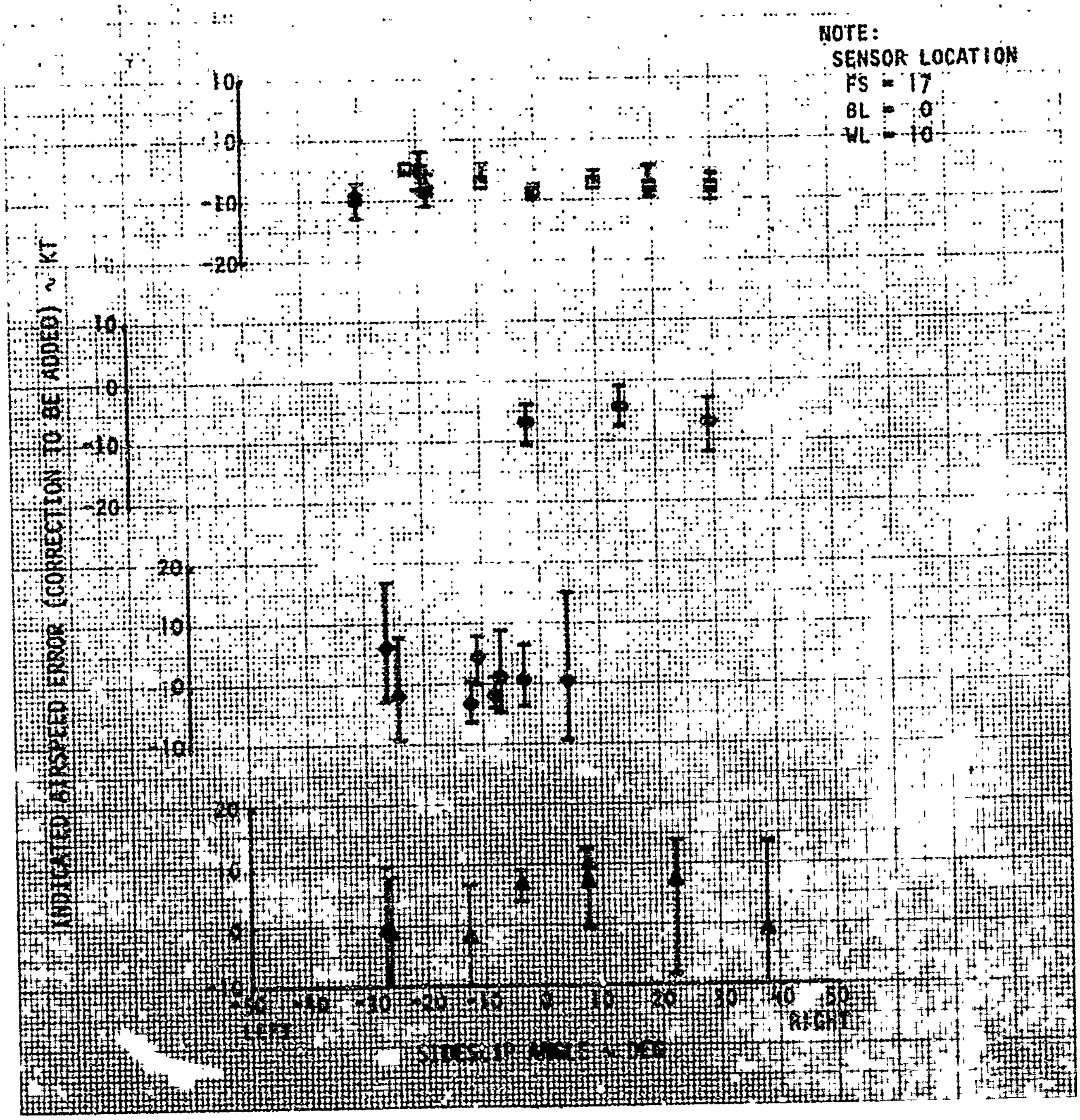


FIGURE 15
EFFECT OF SIDESLIP ON AIRSPEED ERROR
J-TEC SENSOR VA 210 S/N L-72-18 NUH-1C USA S/N 63-8684
ROTOR MAST LOCATION-POST VERTICAL

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	NOMINAL AIRSPEED ~KTAS	FLIGHT CONDITION
△	6400	131.9	-.7	324.	2930	13.5	10	OGE LEVEL FLIGHT
◇	6450	131.9	-.7	325.	3030	13.7	20	OGE LEVEL FLIGHT
○	6390	131.9	-.7	325.	2900	12.9	30	OGE LEVEL FLIGHT
□	6800	131.7	-.7	325.	4890	6.9	50	OGE LEVEL FLIGHT

NOTE
SENSOR LOCATION
FS = 131
BL = 0
WL = 159

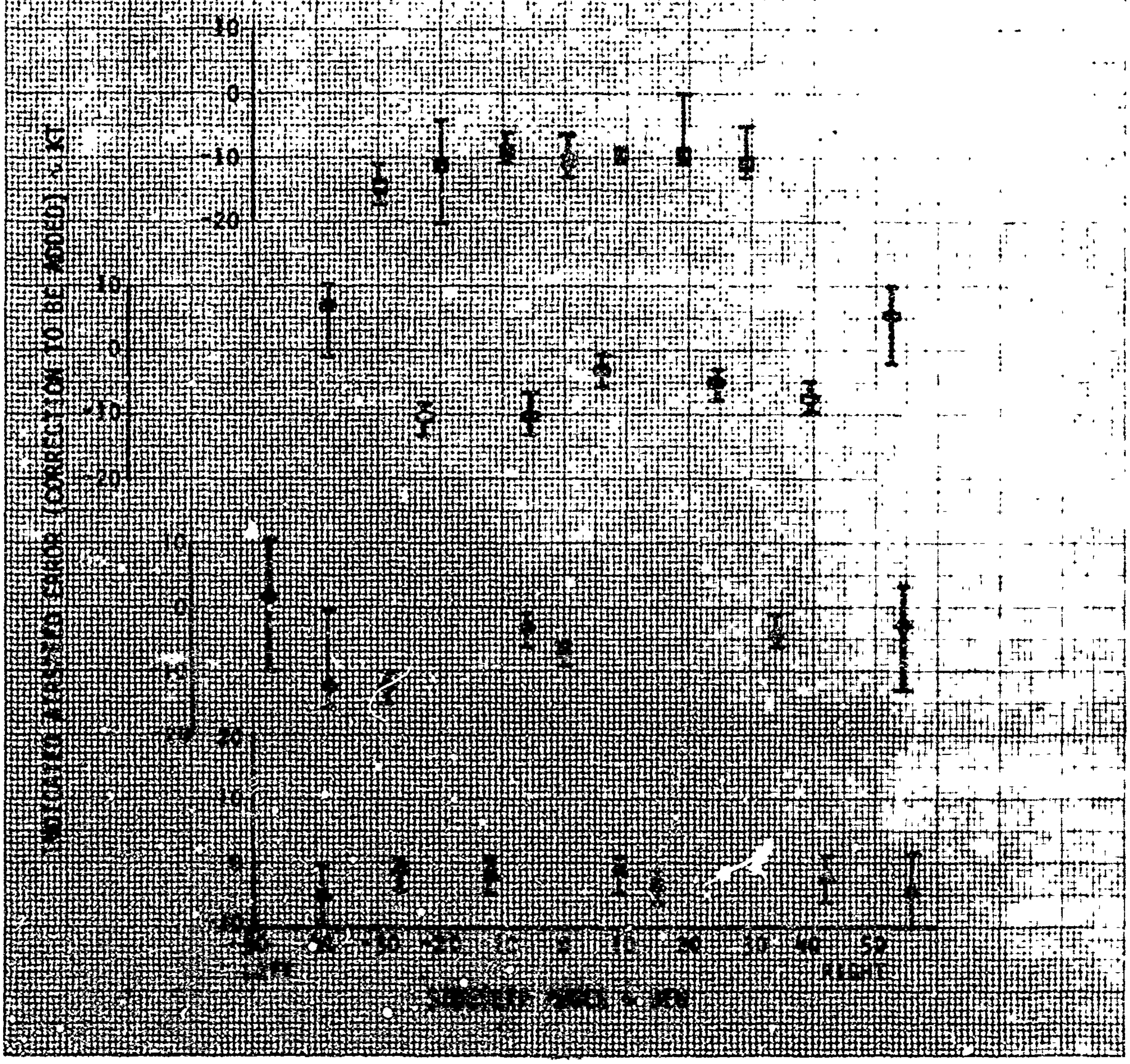


FIGURE 16
EFFECT OF CLIMB AND DESCENT ON AIRSPEED ERROR
J-TEC SENSOR VA 210 S/N L-72-18 NUH-1C USA S/N 63-8684

FM ANTENNA BOOM LOCATION-POST HORIZONTAL

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	NOMINAL AIRSPEED ~KTAS	FLIGHT CONDITION
□	6820	132.1	-.6	327	3460	2.9	50	OGE CLIMB AND DIVE

NOTE:
SENSOR LOCATION
FS = - 8
BL = -28
WL = 36

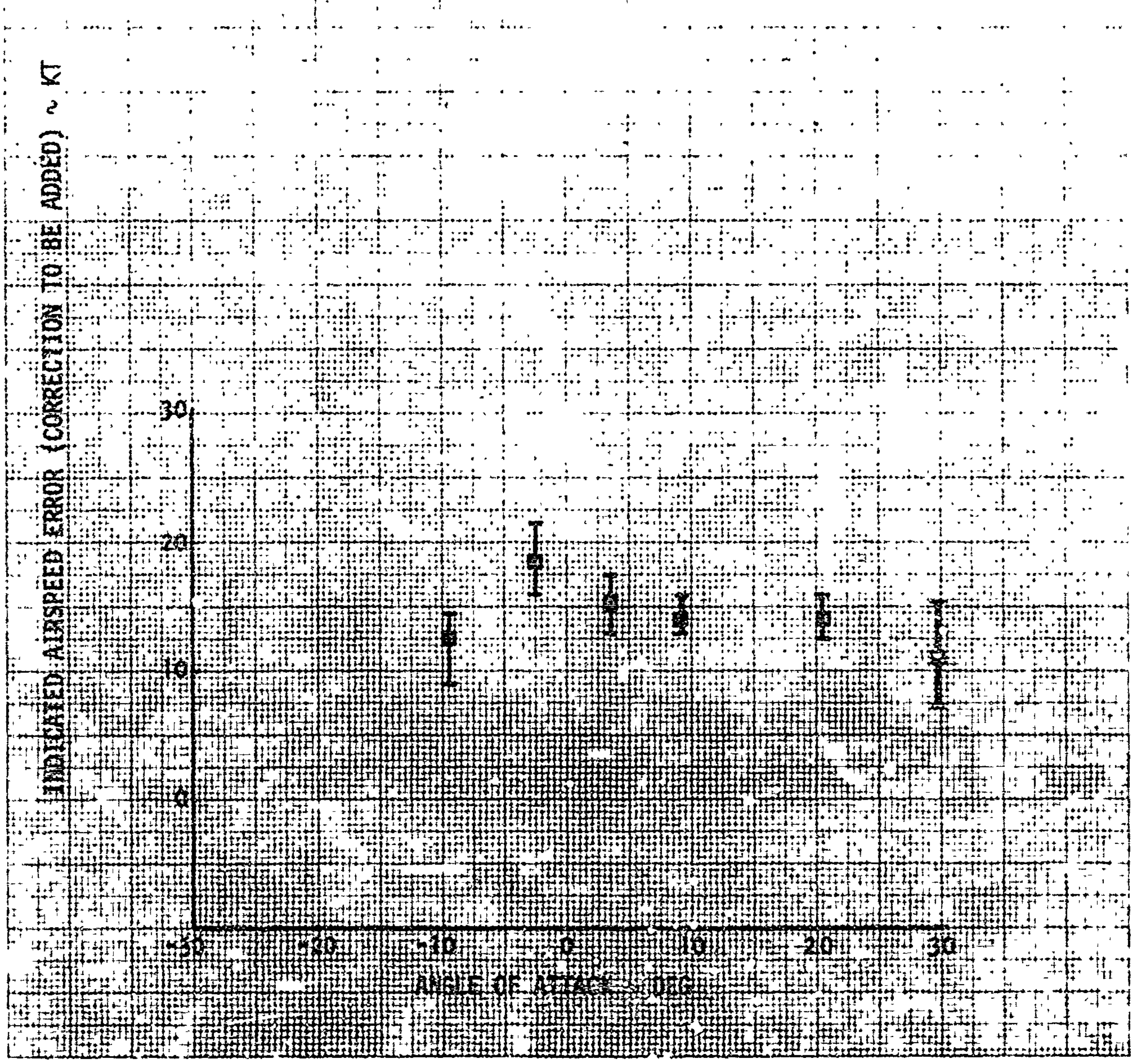


FIGURE 17
EFFECT OF CLIMB AND DESCENT ON AIRSPEED ERROR
J-TEC SENSOR VA 210 S/N 1-72-18 NUH-1C USA S/N 63-8684
AIRSPEED BOOM LOCATION-POST HORIZONTAL

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	NOMINAL AIRSPEED ~KTAS	FLIGHT CONDITION
◻	6730	131.9	-.7	324	5980	4.1	50	OGE CLIMB AND DIVE

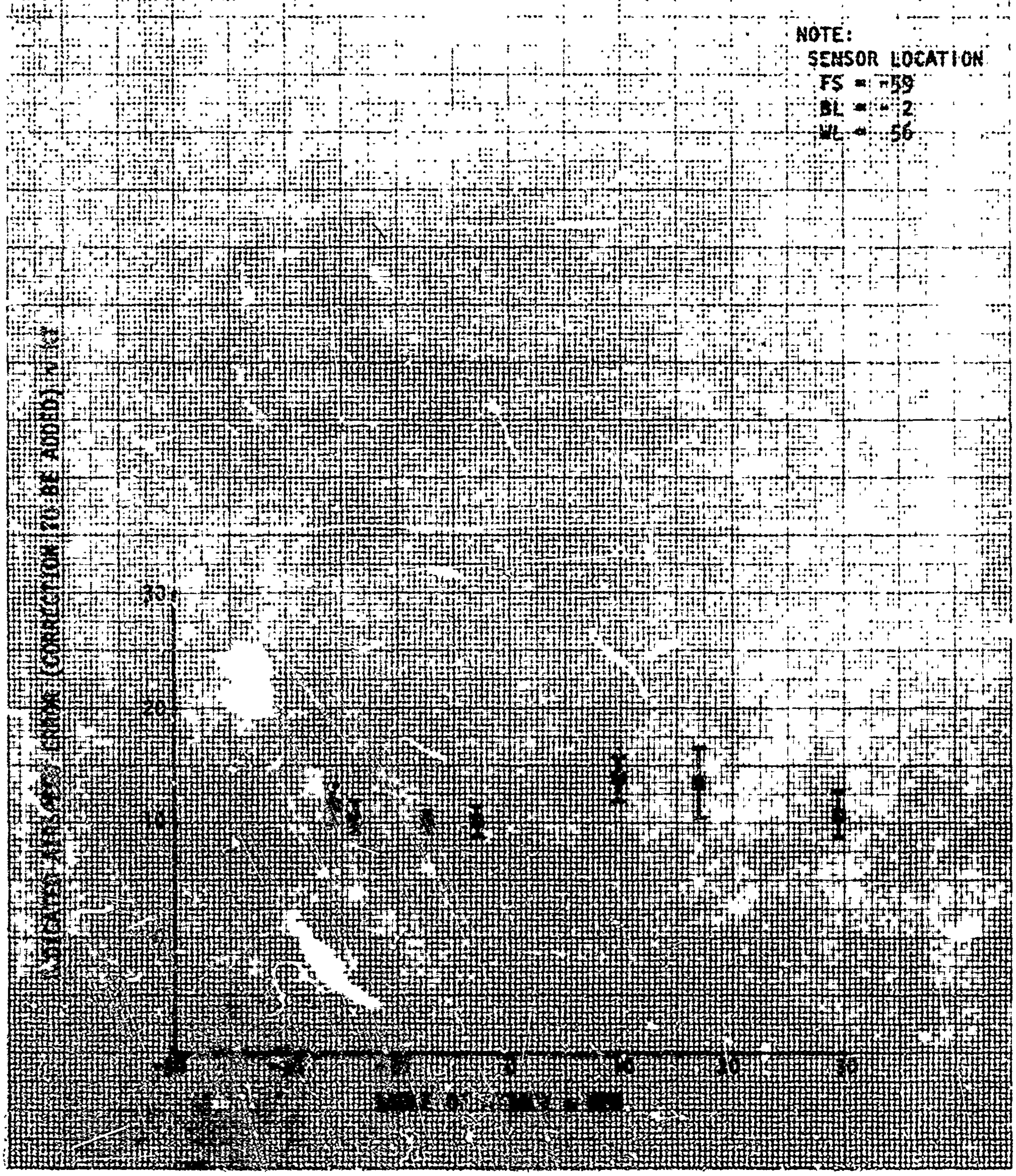


FIGURE 18
EFFECT OF CLIMB AND DESCENT ON AIRSPEED ERROR
J-TEC SENSOR VA 210 S/N L-72-18 NUH-1C USA S/N 63-8684

BELLY LOCATION-POST VERTICAL

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	NOMINAL AIRSPEED ~KTAS	FLIGHT CONDITION
☐	6280	131.8	-.5	325	4800	2.5	50	OGE CLIMB AND DIVE

NOTE:
SENSOR LOCATION
FS = 17
BL = 0
WL = 10

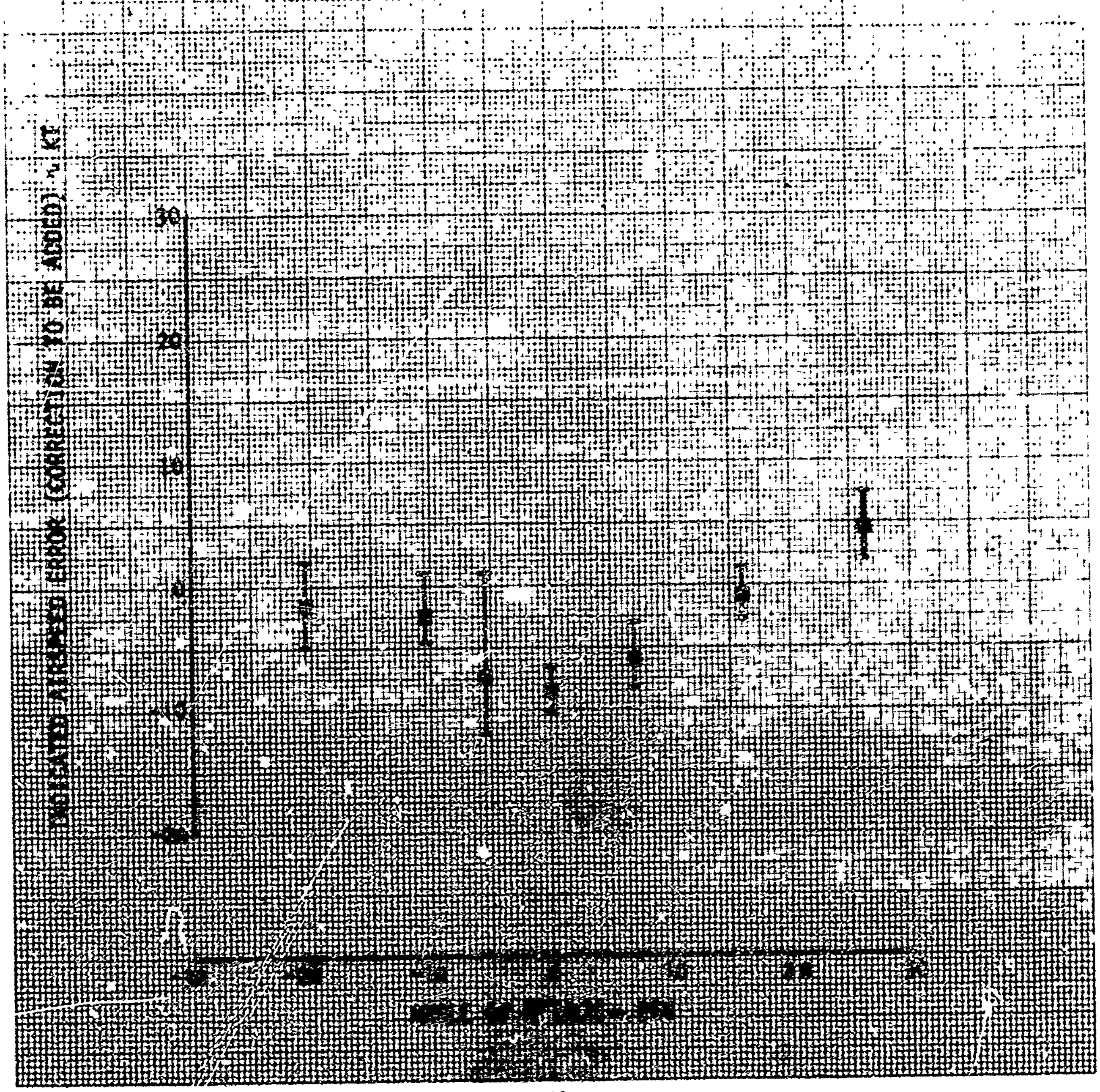


FIGURE 19
EFFECT OF CLIMB AND DESCENT ON AIRSPEED ERROR
J-TEC SENSOR VA 210 S/N L-72-18 NUH-1C USA S/N 65-8684

ROTOR MAST LOCATION-POST VERTICAL

SYMBOL	GROSS WEIGHT ~LB	CENTER OF GRAVITY LONG FS	CENTER OF GRAVITY LATERAL BL	ROTOR SPEED ~RPM	DENSITY ALTITUDE ~FT	AMBIENT TEMP ~°C	NOMINAL AIRSPEED ~KTAS	FLIGHT CONDITION
□	6740	131.7	-.7	325.7	5980	6.0	50	OGE CLIMB AND DIVE

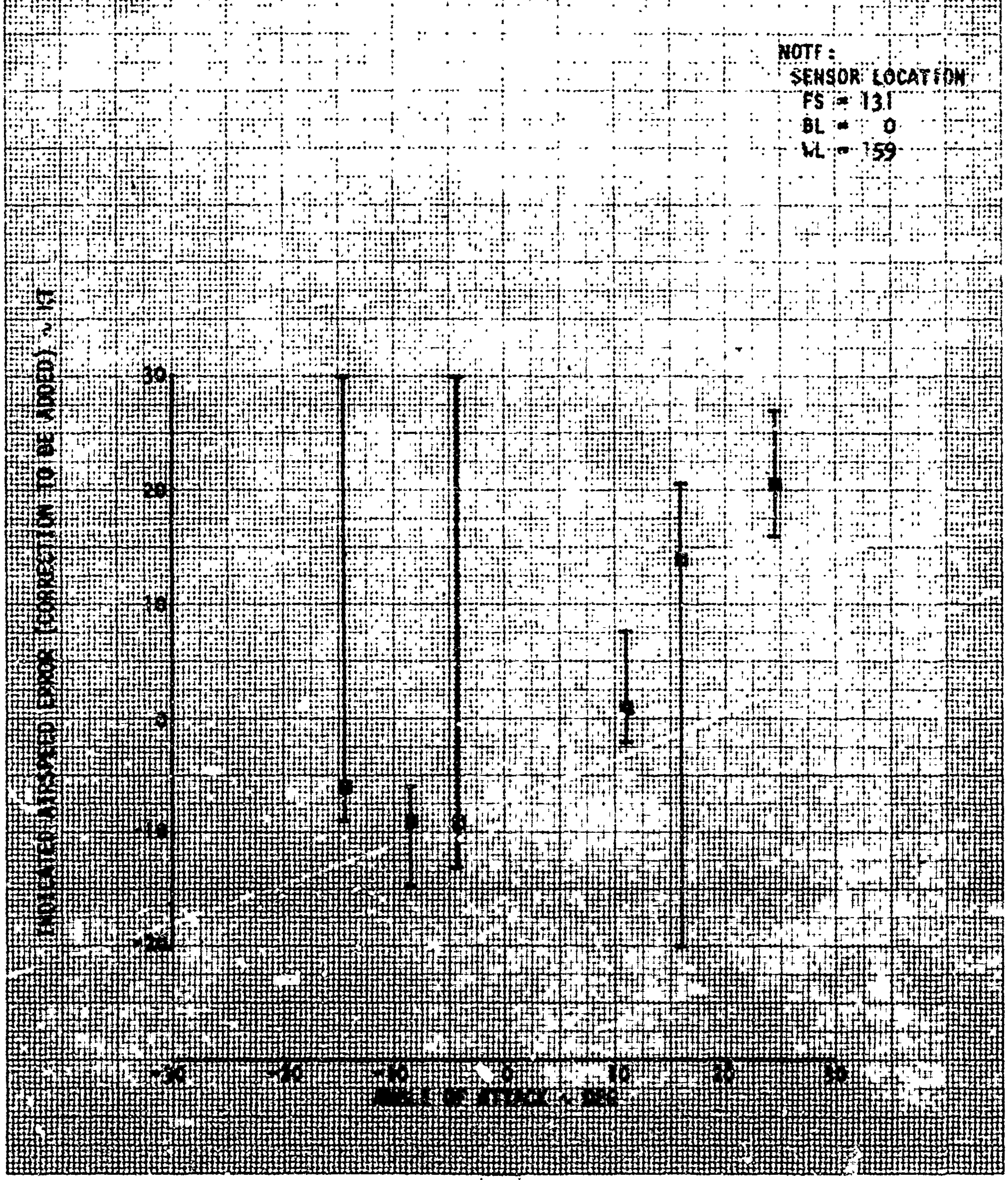


FIGURE 20
WIND TUNNEL AIRSPEED CALIBRATION
J-TEC ASSOCIATES AIRSPEED SENSOR VA-210 S/N L-72-18

NOTE: PITCH ANGLE ZERO
YAW ANGLE ZERO

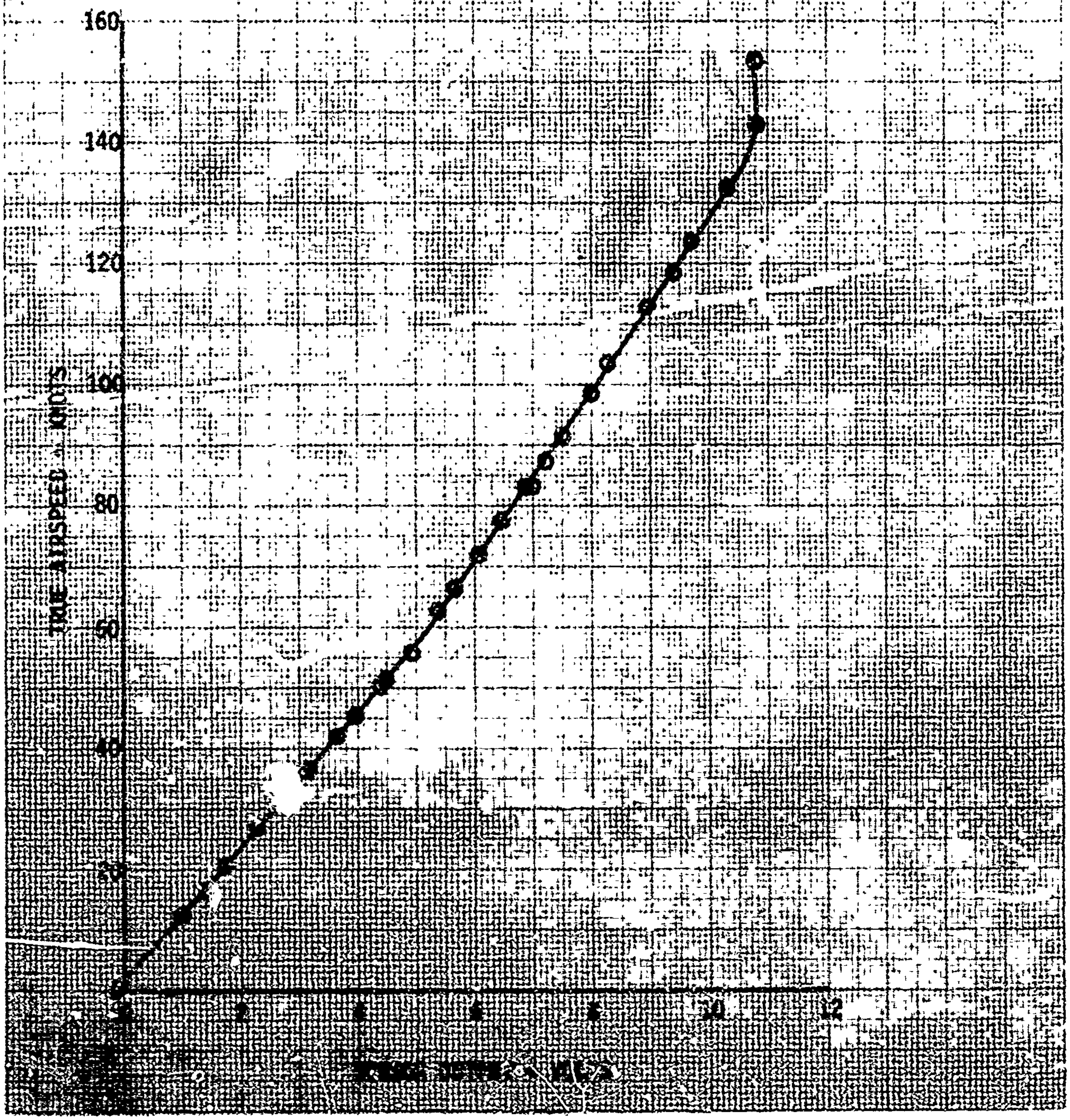


FIGURE 21
WIND TUNNEL AIRSPEED CALIBRATION
J-TEC ASSOCIATES AIRSPEED SENSOR VA-210 S/N L-72-18

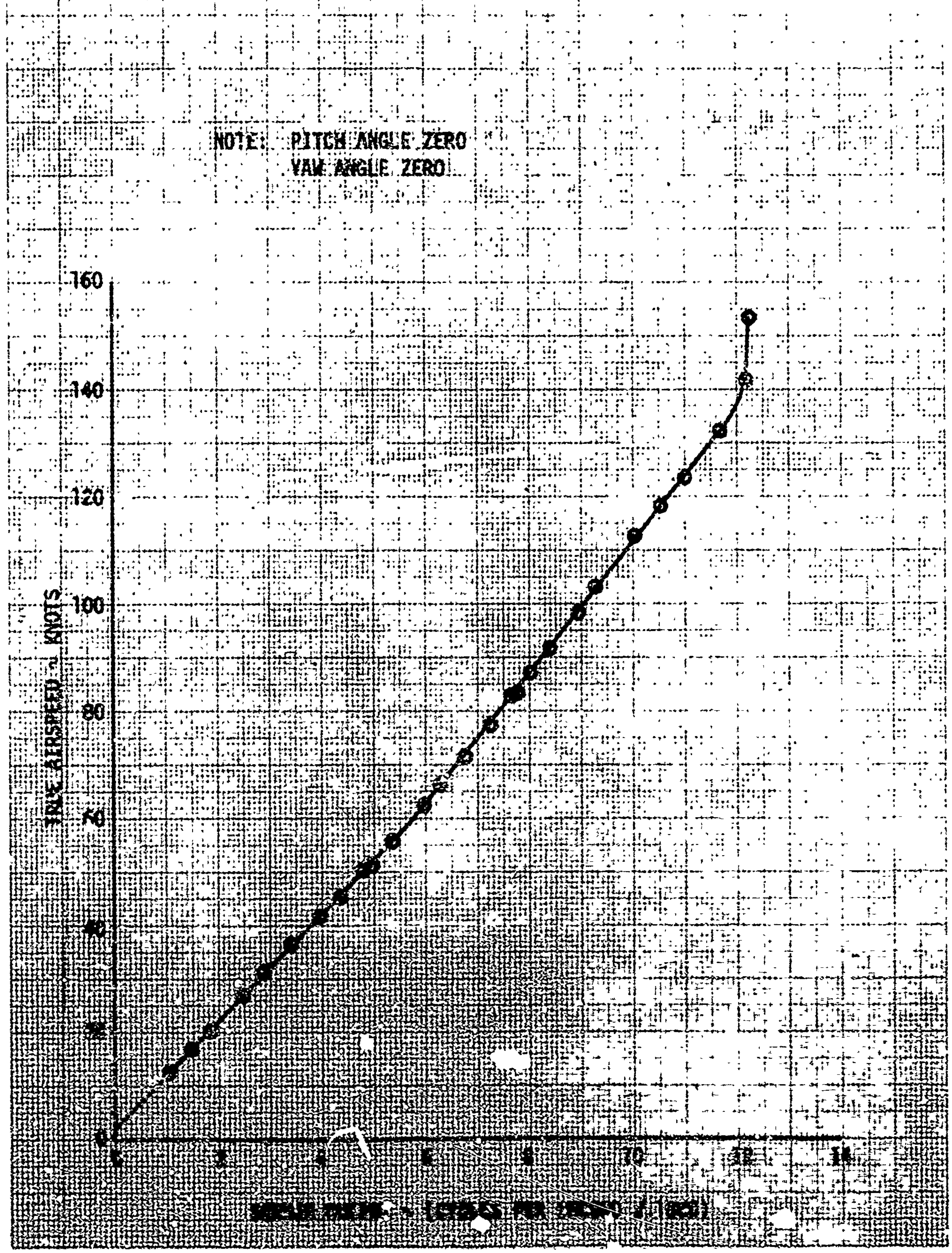


FIGURE 27
WIND TUNNEL AIRSPEED CALIBRATION
J-TEC ASSOCIATES AIRSPEED SENSOR VA-210 S/N L-72-18

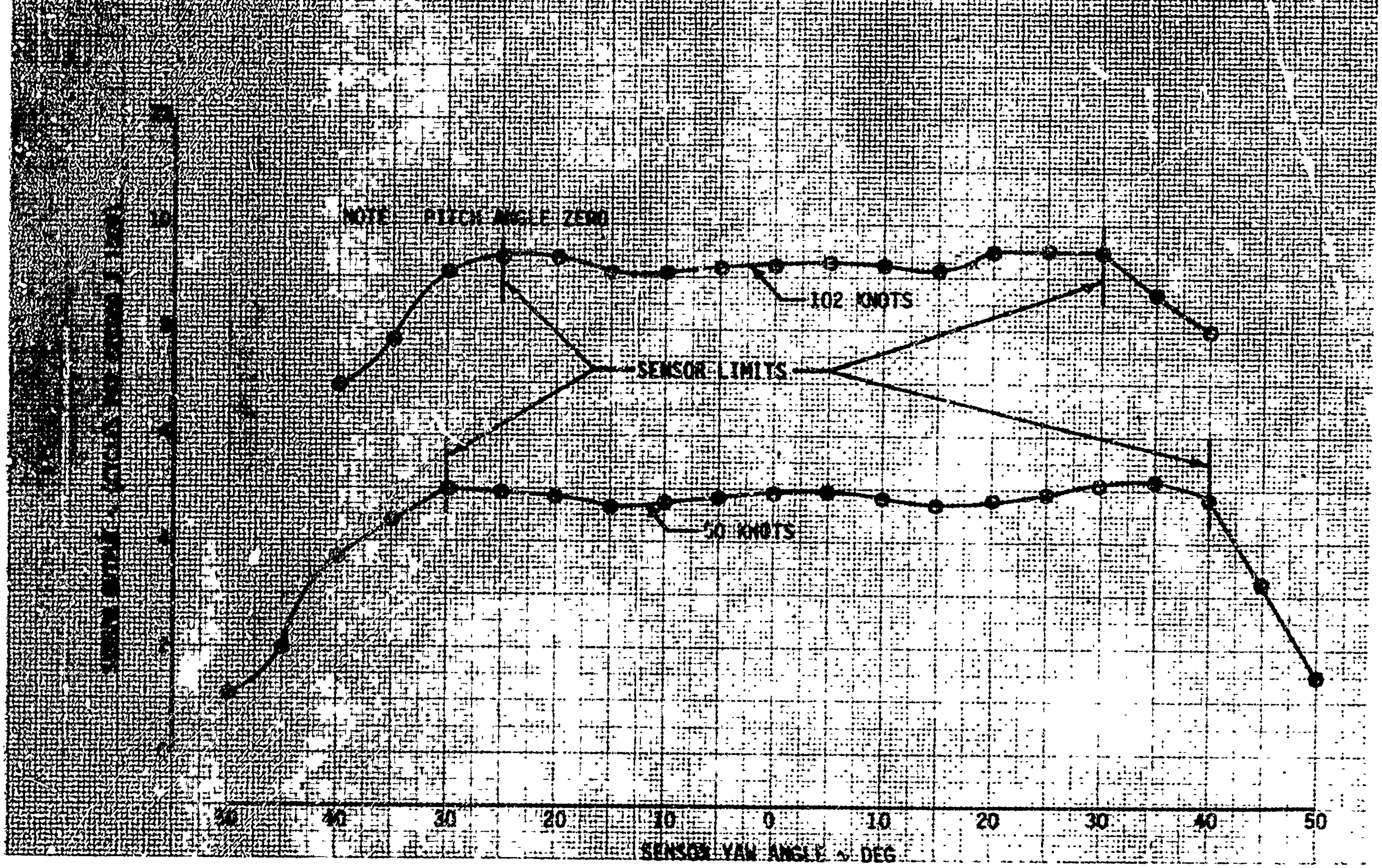
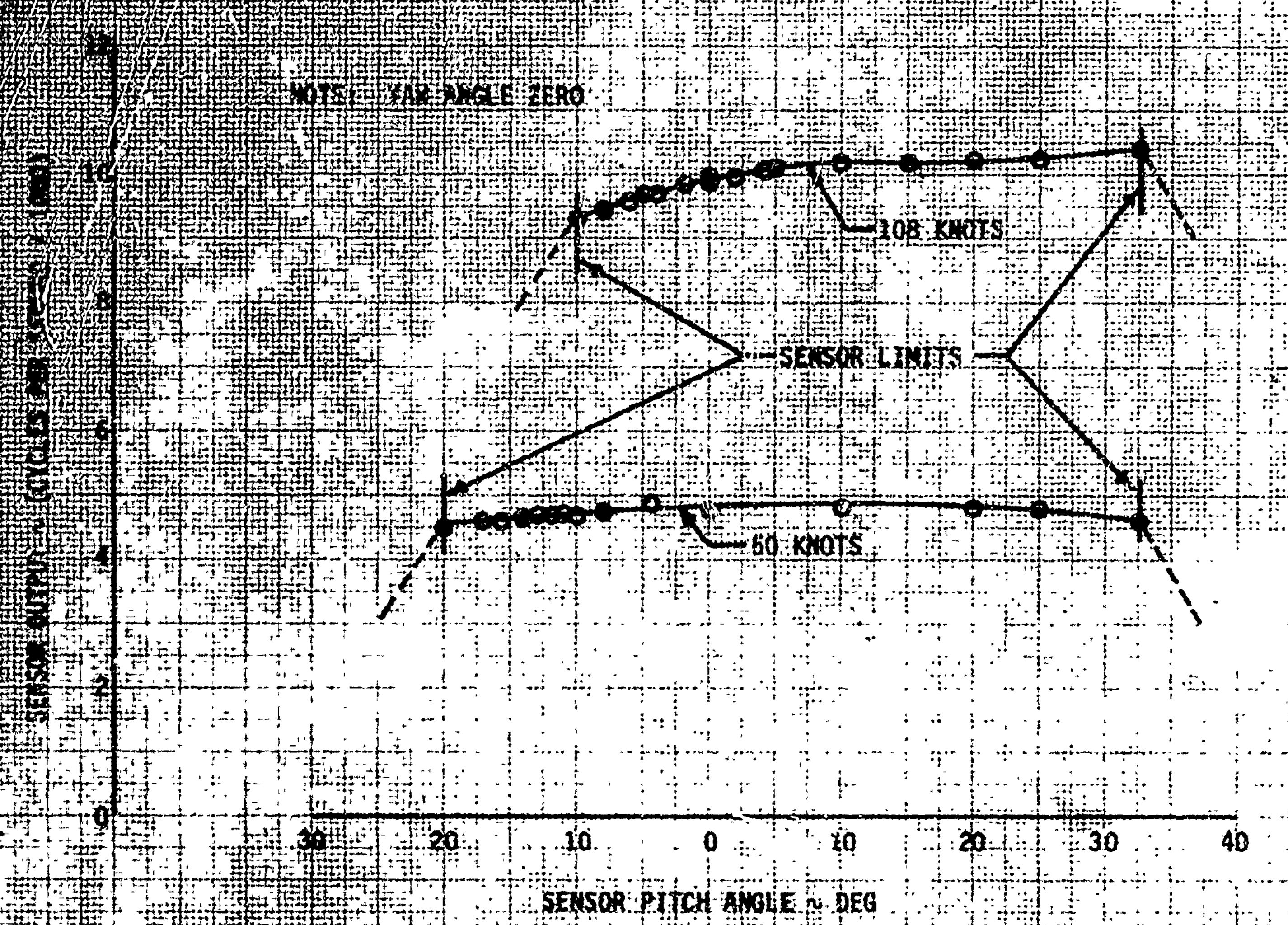


FIGURE 23

WIND TUNNEL AIRSPEED CALIBRATION

J-TEC ASSOCIATES AIRSPEED SENSOR VA-210 S/N L-72-18



APPENDIX C. PHOTOGRAPHS

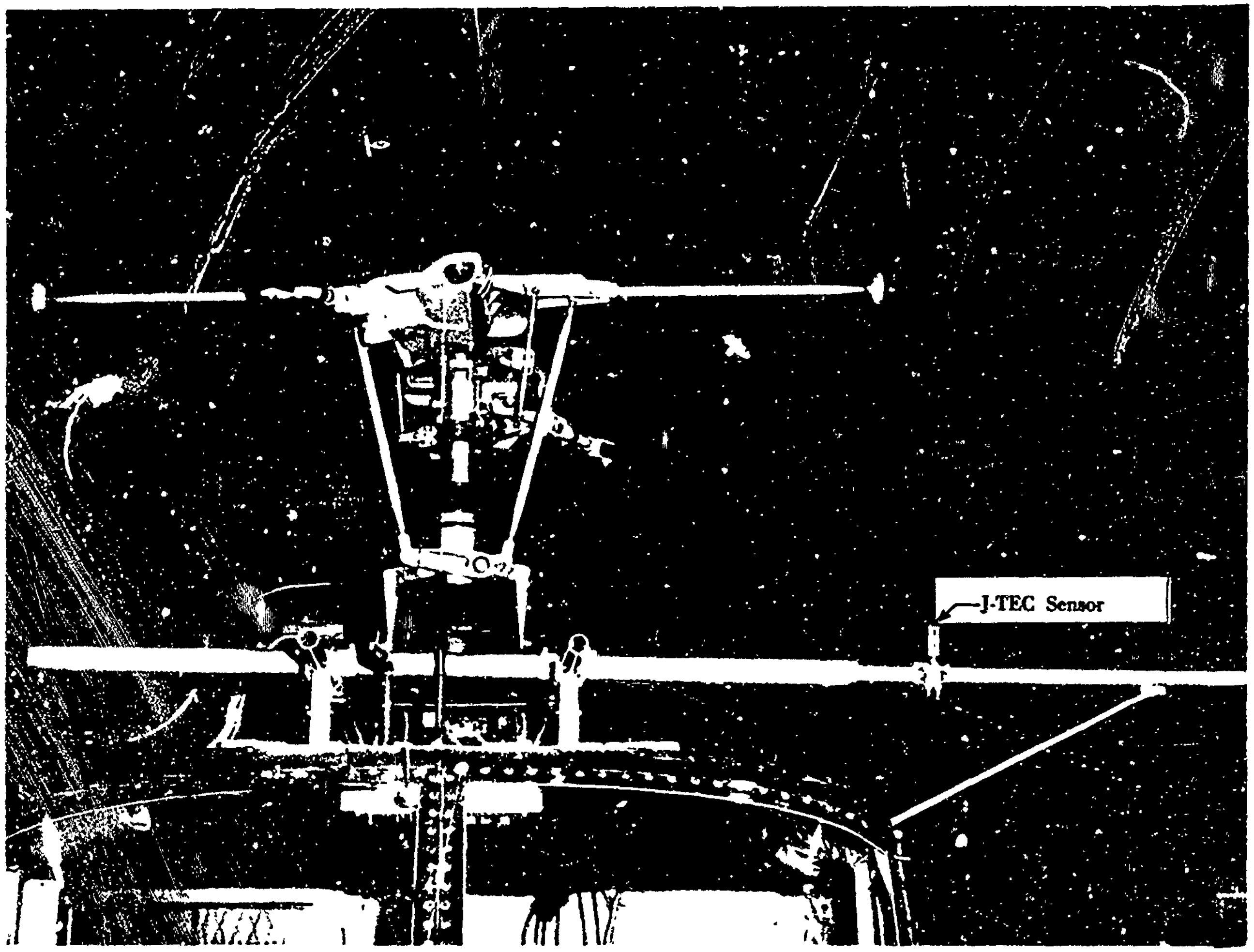


Photo C-1. Cabin Roof Location.

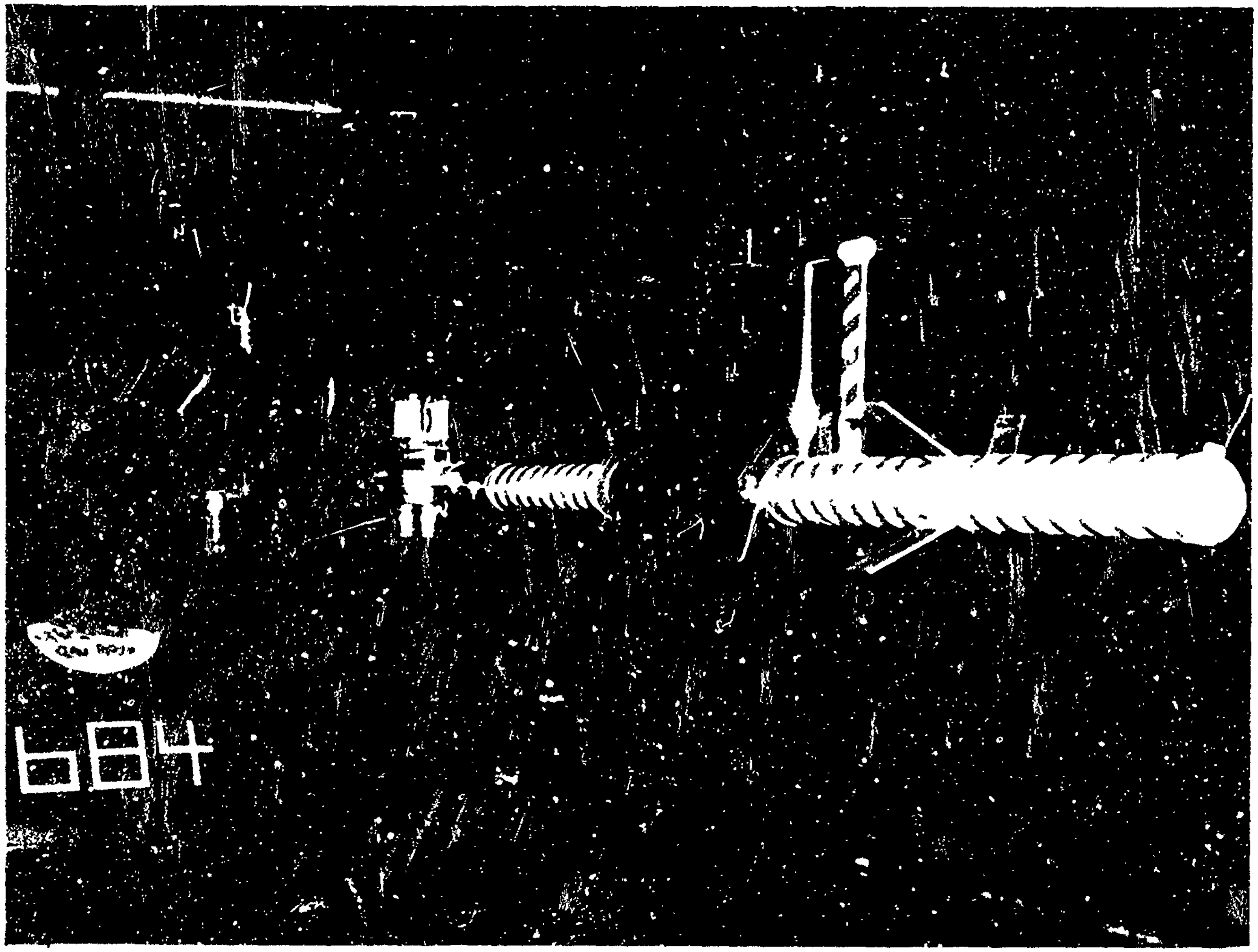


Photo C-2. Airspeed Boom Location.

Photo C-3. FM Antenna Boom Location - Post Vertical.

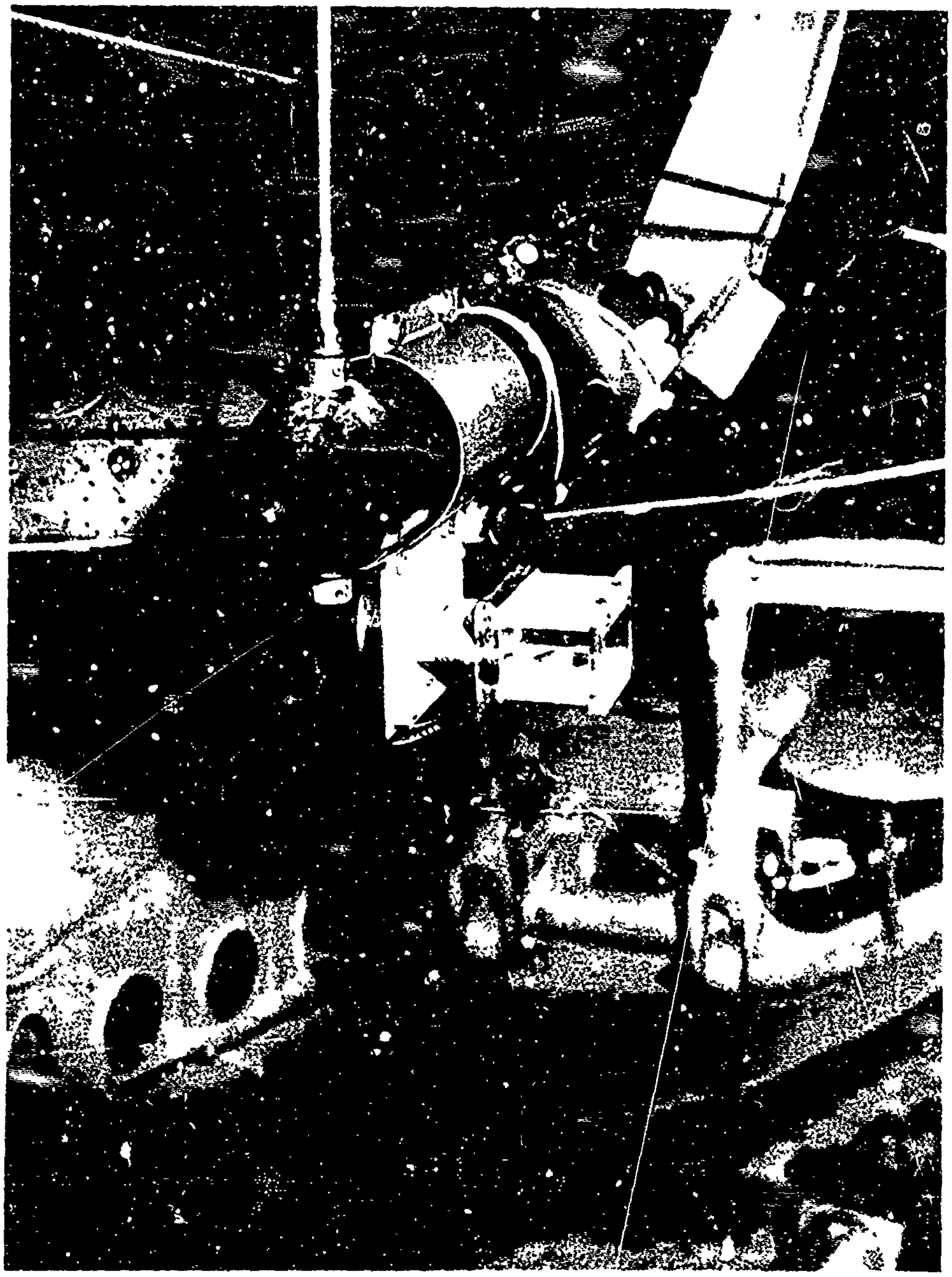


Photo C-4. FM Antenna Boom Location - Post Horizontal.

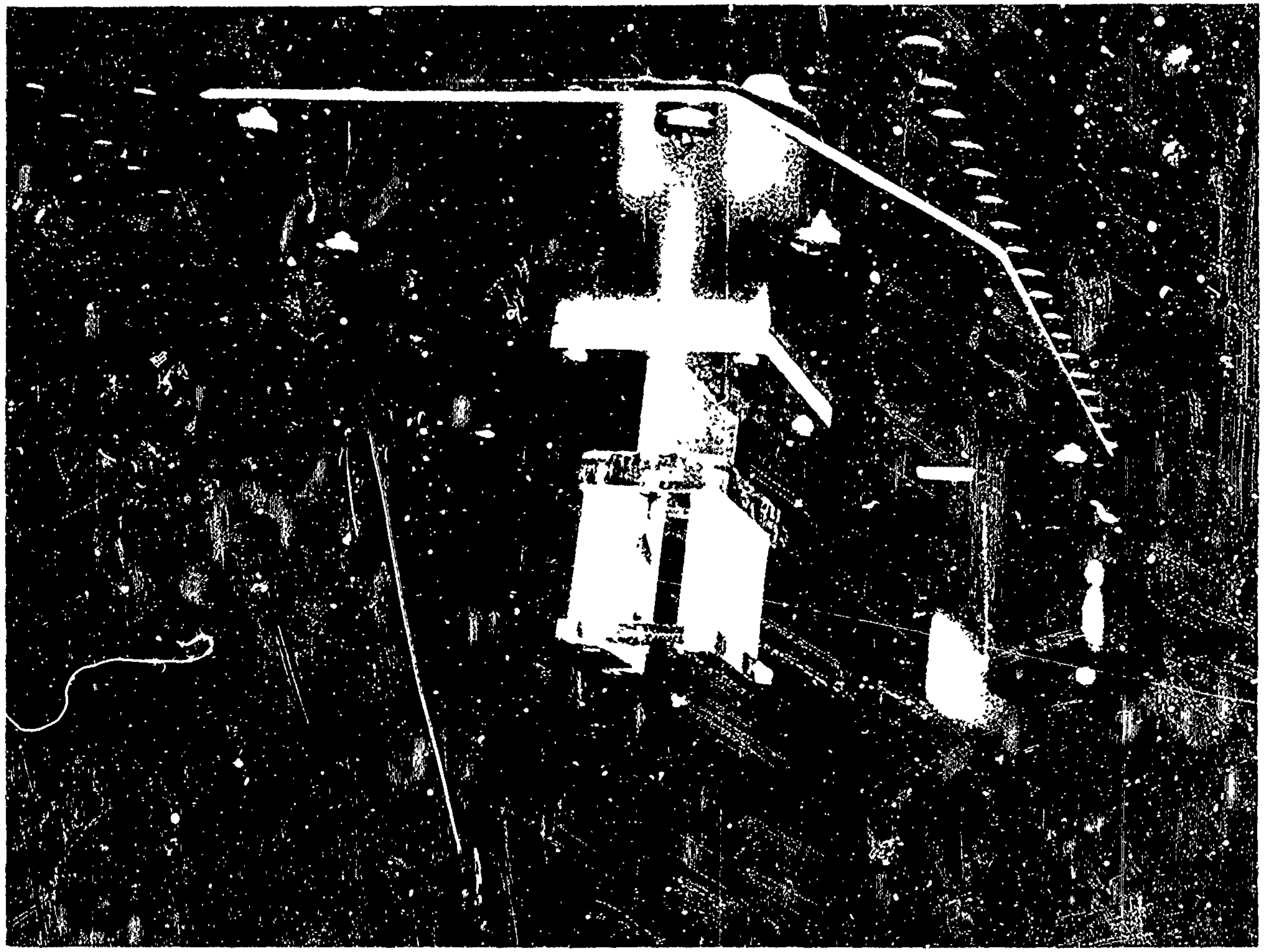


Photo C-5. Belly Location.

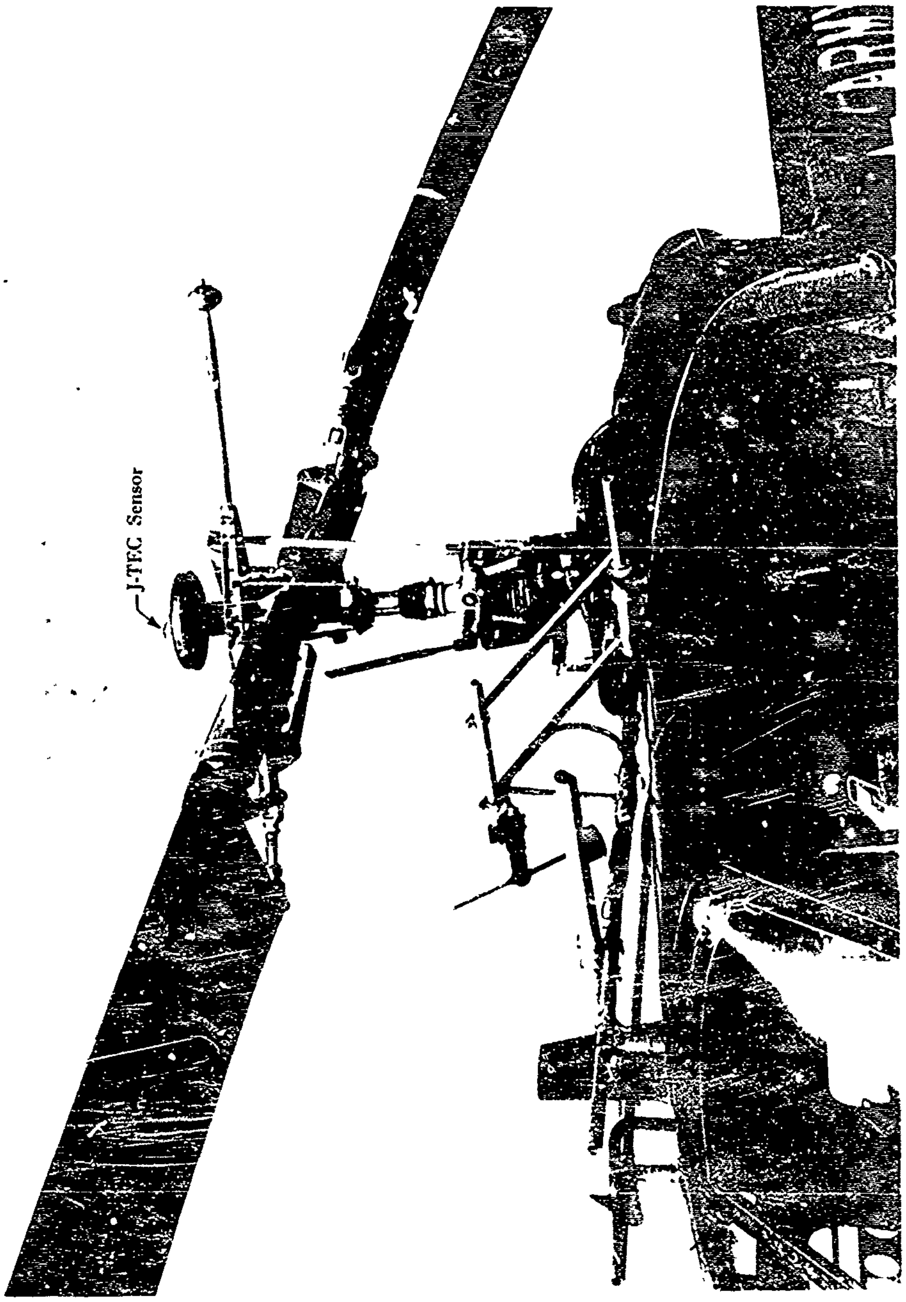


Photo C-6. Rotor Mast Location.